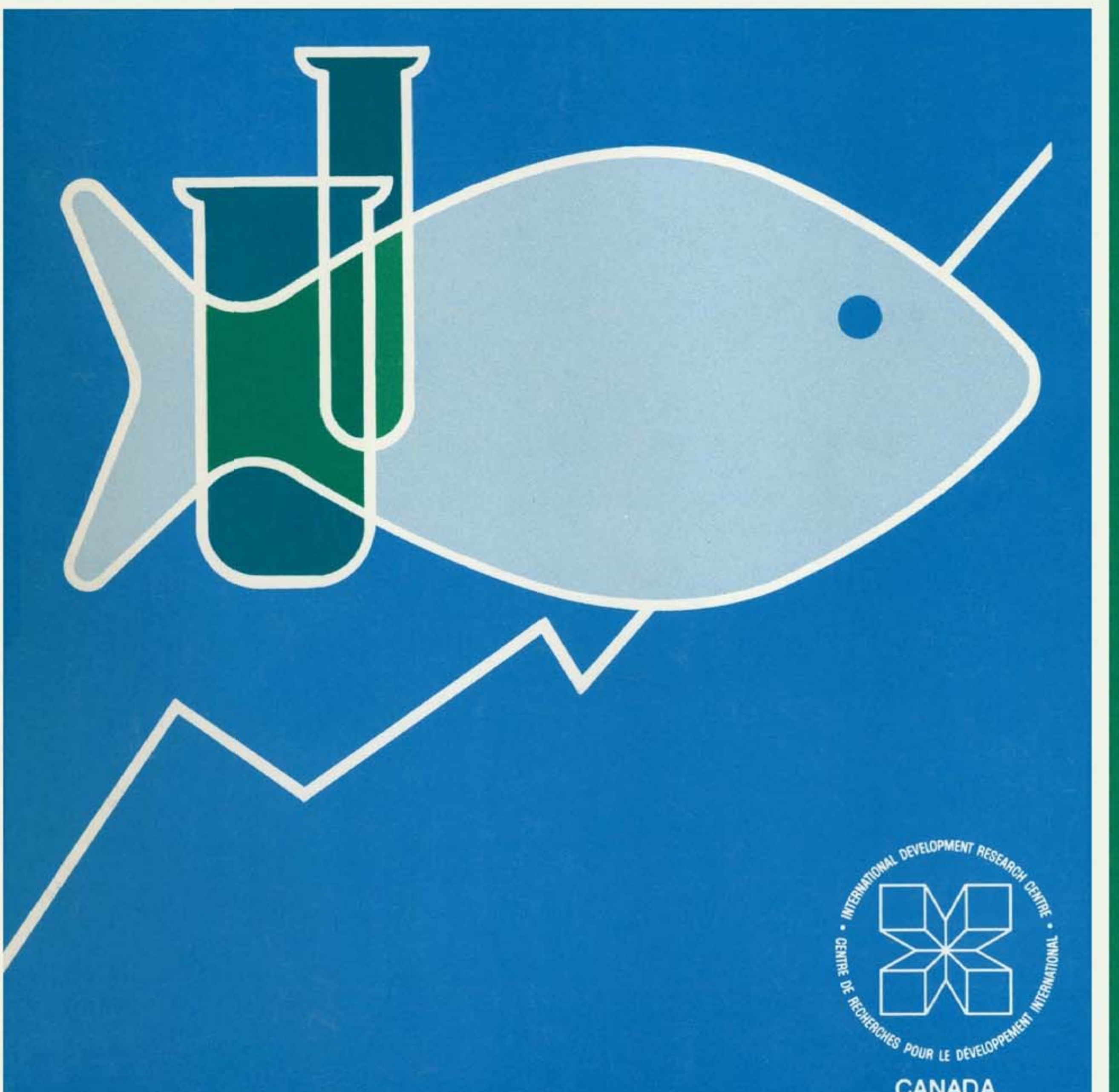
IDRC-193e

Aquaculture Economics Research in Asia



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Aquaculture Economics Research in Asia

Proceedings of a workshop held in Singapore, 2–5 June 1981

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Résumé

Cette publication contient une version revue des communications présentées à l'atelier sur la recherche intéressant l'économie de l'aquiculture en Asie, tenu à Singapour du 2 au 5 juin 1981. Les Divisions des sciences de l'agriculture, de l'alimentation et de la nutrition et des sciences sociales du Centre de recherches pour le développement international (CRDI) et le International Center for Living Aquatic Resources Management (ICLARM) ont conjointement réuni des biologistes et des économistes des pêches de neuf pays d'Asie du Sud et du Sud-Est. L'atelier visait à montrer l'utilité et à favoriser l'utilisation de l'analyse économique dans la recherche en aquiculture et à aider à augmenter les compétences de recherche en économie de l'aquiculture en Asie. L'atelier a traité surtout des analyses microéconomiques des systèmes de production aquiculturaux déjà implantés et au stade expérimental. Il a comporté aussi une revue et une discussion sommaires de quelques-unes des grandes considérations socio-économiques reliées à la contribution de l'aquiculture à la société en général et au rôle du système de marché dans l'affectation des ressources à l'aquiculture et aux autres secteurs de l'économie.

Resumen

Esta publicación es una version editada de los trabajos presentados en Singapur, del 2 al 5 de junio de 1981, durante el taller sobre investigación en la economía de la acuocultura en Asia. Las divisiones de Ciencias Sociales y de Ciencias Agrícolas, Alimentos y Nutrición del Centro Internacional de Investigaciones para el Desarrollo, en colaboración con el International Center for Living Aquatic Resources Management (ICLARM), invitaron a biólogos y economistas especialistas en piscicultura de los países del Sur y Sudeste Asiáticos. La meta del taller era demostrar el uso del análisis económico para la investigación en acuocultura y estimular su uso, así como mejorar la capacidad de investigación en economía de la acuocultura en Asia. Se prestó atención especial a los análisis microeconómicos de sistemas de producción de acuocultura experimentales y existentes, aunque también se presentaron una reseña y discusión limitadas, relativas a algunas consideraciones socioeconómicas más amplias de la contribución de la acuocultura a la sociedad como un todo y al papel del sistema de mercado en la distribución de recursos a la acuocultura y a otros sectores.

Contents

Foreword

Interest in the development of aquaculture as a manageable food production system and as a source of livelihood for Asian peoples has intensified considerably during the past decade. This escalation of development efforts stems mainly from: the need to produce additional protein from fish to meet the demand created by rapidly increasing populations, the leveling off in world catch from conventional fish stocks (capture fisheries), the expected reduction in catch by some of the developing countries that are major fish consumers because of the extension of national economic zones in marine waters, and the continuing need in many countries to find opportunities for productive livelihood for growing numbers of peoples with very limited access to natural resources. Current aquaculture practices in the tropics are at an elementary level and husbandry techniques are only now evolving. The life cycles of only a small number of species are fully understood and studies of genetics and the development of more desirable hybrids are in their infancy. In this sense, aquaculture lags behind husbandry sciences in poultry and livestock, the other major sources of animal protein. Also, much like capture fisheries until the 1950s, aquaculture research and development has been the preserve of biologists and other technologists. While the body of literature on the biological and technological aspects of aquaculture in the tropics is steadily increasing, little information on economic aspects is available. Moreover, available economic studies are often based on very limited samples or observations and tend to be descriptive rather than rigorously analytic.

However, the potential scope for aquaculture economics research is wide. As aquaculture develops, economists will be called upon to analyze current production and marketing practices, particularly in the private sector, and to evaluate improved husbandry techniques as they are developed. Economic research can help appraise the current practices and potential of aquaculture by: analyzing the production and marketing aspects of both experimental and existing culture systems, assessing the role and contribution of aquaculture as compared with other sectors in national economies and international trade, and evaluating development projects and the institutional and cultural environment in which aquaculture development is expected to take place.

Both the International Development Research Centre (IDRC) and the International Center for Living Aquatic Resources Management (ICLARM) have initiated and supported aquaculture economics research. IDRC has been encouraging economic analyses of the various research projects it has been funding to develop production systems that can produce relatively high, stable yields, while requiring low or modest levels of capital input. ICLARM's current economics activities centre upon analysis of existing milkfish production systems in the Philippines and Taiwan, catfish production in Thailand, and on country case studies of aquaculture trends and development prospects. Both organizations believe that there is a pressing need to bring about a more coordinated approach to aquaculture economics research so that the results of such research can support the ultimate objective of increasing production from an economically viable aquaculture sector. It is particularly important that greater contact be encouraged between biologists, economists, and other social scientists involved in aquaculture research to foster interdisciplinary and multidisciplinary research on existing and new aquaculture systems for production and on marketing, to better understand the socioeconomic environment in which aquaculture systems exist, and to assess the economic and social effects of new aquaculture technology.

It was for this reason that the Agriculture, Food and Nutrition Sciences and Social Sciences divisions of IDRC and ICLARM collaborated to invite fisheries biologists and economists from nine South and Southeast Asian countries to Singapore on 2–5 June 1981. Participants discussed how economics could contribute to the assessment and development of aquaculture production and marketing systems and to the better understanding of the social and economic functions aquaculture plays in a particular society. The workshop focused on this geographic region because it is the area with the highest level of aquaculture production in the tropics. To foster close collaboration and an active exchange of views, participation was limited to a small group. Furthermore, the workshop purposely brought together participants with quite different disciplinary backgrounds and research experience to initiate an active dialogue.

The overall objective of the workshop was to demonstrate and encourage the use of economic analysis for aquaculture research and to help increase the research capacity for aquaculture economics in Asia. Attention was focused largely on microeconomic analyses of existing and experimental aquacultural production systems, although a limited review and discussion of some of the broader socioeconomic considerations related to aquaculture's contribution to society as a whole and to the role of the market system in the allocation of resources to aquaculture and other sectors were included.

IDRC and ICLARM are happy to have cosponsored this workshop and wish to express their gratitude to the resource persons and to the workshop participants for their valuable contributions and comments. This was the first jointly sponsored meeting in this field between two different divisions of IDRC (Agriculture, Food and Nutrition Sciences Division and Social Sciences Division) and ICLARM. It is hoped that increased collaboration will be possible in the future and that the results of this workshop will encourage continued and expanded collaboration between biologists and economists in future aquaculture research.

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Introduction

Aquaculture, defined as the culture and husbandry of aquatic organisms, has a long, even if relatively little-known, history. Over centuries, the practice of aquaculture in natural and man-made ponds has become widespread, particularly throughout much of Asia, where fish and shellfish form an important part of the average family's diet. Aquaculture has developed within agricultural communities through a process of trial and error and the resulting production technology has a limited scientific base. There is also a shortage of recorded data on inputs, outputs, and management techniques. However, although the techniques have remained virtually unchanged, it is widely believed that improved methods could significantly increase production. Estimates vary as to the potential contribution of aquaculture to world fish supplies. However, a doubling or tripling of the present production of 6×10^6 t/year by the end of the century seems realistic with the wider application of known aquaculture methods. Even greater production may be technically feasible if significant advances in both basic and applied research are achieved and applied.

Aquaculture can have several advantages over capture fisheries. For example, aquaculture is a technique of stock raising, not hunting or gathering and, therefore, is often a more efficient use of time and effort. Certain environmental conditions can be largely controlled and, as in animal husbandry, genetic improvement can be used to increase yield. Aquaculture can also be undertaken on land poorly suited for agriculture. Fish are efficient converters of feeds and of low-quality plant materials and wastes. In many cases, fish can be reared with no additional feed beyond what is naturally available in their environment or as the result of fertilizer enrichment. It is also possible that the market demand for fish from aquaculture production can be expanded more easily than for wild fish. Through controlled production, fish farmers can guarantee a certain quantity and quality of production, market their produce when natural supplies are seasonally low or not available, and in some cases exploit the potential for selective production to meet consumer preference for taste and other market requirements: such control is not possible in most capture fisheries.

Within the past decade, a sizable amount of effort and resources has been committed by the national governments of developing countries and by international agencies to expand aquaculture production through research and the application of technology. In some countries, growth in aquaculture production has been notable; in others far less has been achieved than originally anticipated. The economic scale of aquaculture enterprises and organization of production also vary considerably from country to country. In some countries, large-scale commercial enterprises employing wage labour forces prevail; in other countries there are more small enterprises with greater participation in management and ownership of those who work in aquaculture enterprises. The reasons for constrained production are many, a major one in many countries being the novelty of aquaculture as a major food production sector of the national economy. The scale of production and organization of production of aquaculture enterprises constrain and determine the opportunities for remunerative participation in the industries, and also affect both the costs of production and the price of fish protein to the various consumer groups. As a new industry is established or an old one is being transformed by the application of new technology, many technical, economic, institutional, and cultural problems as well as opportunities arise.

Generally, as aquaculture has expanded, so has the volume of technical literature. To date, biological and technical problems have received most of the attention because biologists have by and large been the principal researchers. Biologists have focused and are continuing to focus on ways to overcome constraints to production and to modify and/or intensify traditional systems. In addition to traditional pond production, alternative systems and techniques such as polyculture (a mix of complementary species), integrated animal/crop/fish systems, cage and pen culture, greater utilization of naturally productive bodies of water and appropriate herbivorous species of fish, and raft and rack culture of shellfish are all being tried. At the same time, some major biological issues such as induced breeding of fish in captivity, prevention of disease, nutritional requirements of indigenous and exotic species, and selective genetic improvement are being studied.

However, in spite of this ever-increasing biological research activity, inadequate attention has been devoted to other, equally important, problem areas and to the interplay among them. The viability of aquaculture technology involves more than the study of its biology and technology. For example, economics must be used to determine efficiency of resource allocation. Reliable information on the economics of existing aquaculture systems and the economic viability of the new technology is often lacking. In addition to the economics of production, evaluation of markets including demand, marketing infrastructure, and marketing channels is important. The size and expected growth of the market, factors affecting demand (i.e., population and incomes), competition with either other local or imported supplies, and marketing costs are all key factors in the successful establishment and development of aquaculture enterprises.

An understanding of the relationship between existing social and cultural practices and resource allocation in a society is an important element in the development and introduction of aquaculture technology. Although there have been studies of the sociocultural aspects of aquaculture, there is little information available with respect to the socioeconomic and cultural impacts of new aquacultural technology. For it to be successfully applied, both its demand and combination of resources and its resulting products must be compatible with individual and community cultural practices. More information is needed on how changing resource allocation to and within aquaculture production relates to national development policies.

These proceedings are an effort to encourage such multidisciplinary analysis of aquaculture systems to generate a better understanding of the ways in which economic analysis can contribute to the development and application of new technology so that the potential benefits both to those engaged in production and to consumers of fish can be realized and maximized. Three major subject areas were reviewed during the workshop: microeconomic analysis of existing aquaculture production, microeconomic analysis of experimental aquaculture technology, and social welfare economic considerations for aquaculture development. Because of the varied backgrounds of the participants at the workshop and the expected readers of this volume, each of the three subject areas is introduced by a paper on economic principles and concepts relevant to aquaculture. Case study presentations of research methodology and economic analysis undertaken in various countries in Asia follow the first two of these introductory papers. Although some of the statements and questions contained in this volume may seem elementary to some readers, they are included to demonstrate the need for greater interaction and cooperation between the various disciplines involved in aquaculture research. The final part of the proceedings is a summation of the overall conclusions and recommendations arising from the meeting. Two appendices have also been included: working definitions of economic and statistic terms, and a selected bibliography.

It is hoped that readers, regardless of disciplinary background and research experience, will find the proceedings both interesting and informative. In the future, greater collaboration among researchers conducting biological, social, and economic research may lead to more successfully developed and applied aquacultural technology.

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Session I
Microeconomic Analysis of Existing Production Systems

Microeconomics of Existing Aquaculture Production Systems: Basic Concepts and Definitions

Ian R. Smith[1]

The main objective of this paper is to provide an introduction to the methodology used in the case studies that follow. The paper focuses on the role of relative prices in farmers' production behaviour and presents a model for explaining output variations among farmers. In the context of this production mode, the concepts of output elasticity, economies of scale, and technical and economic efficiency are explained using illustrative examples. The type of data used and the estimation techniques are briefly described and the distinction between average and frontier production functions is emphasized.

A typical aquaculture resource system (Fig. 1) has subsystems of procurement, transformation, and delivery (Ruddle and Grandstaff 1978). The procurement subsystem includes the factor markets for stocking materials (seed or fry) and other inputs, such as land, water, labour, feed, fertilizer, and managerial expertise. Many aquaculture systems are dependent upon wild fish stocks to provide fry for stocking in rearing enclosures, although hatcheries are becoming increasingly important for certain species. The transformation subsystem includes the production process by which seed stock is reared to marketable size. Finally, the delivery subsystem includes the various marketing intermediaries and consumers, both domestic and foreign.

The concepts and terminology to be discussed are drawn primarily from neoclassical production economics theory. In the case studies, attention will be directed to addressing such questions as: Which inputs are significant in explaining variation in output from various aquaculture producers? Are there economies of scale in aquaculture production? (If all inputs are doubled, will output also double, or more than double, or less than double?) Are producers making optimal use of inputs? Are they technically and economically efficient? What constraints inhibit increased productivity and profitability of existing aquaculture resource systems?

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The Underlying Biological/Economic Relationship in Production

Output from an aquaculture production system is a function of the inputs applied in the production process. The level of output depends upon environmental factors (soil pH, water salinity, etc.), stocking rates, supplementary inputs (feed, fertilizer, pesticide), labour (hired and family), managerial expertise, and the underlying technology used. The deep water pond system for rearing milkfish in Taiwan using the "plankton" method, for example, is a different technology from the shallower ponds of the Philippines that use the filamentous algae method. The relationship between inputs and output is commonly referred to as the production function, and much of production economics dwells on methods of determining this physical input-output relationship, adding an economic component, and interpreting producer behaviour based on the results.

Output, then, is a function of variable and fixed inputs. By examining progressively complex representations of this relationship, it is possible to establish the link between (and differences between) biological and economic considerations of aquaculture producers.

Let us begin with the simple unconstrained case (no capital constraint) of one output and a single variable input. This case can be illustrated in a two dimensional diagram (Fig. 2) where output (e.g., fish) is dependent upon the quantity

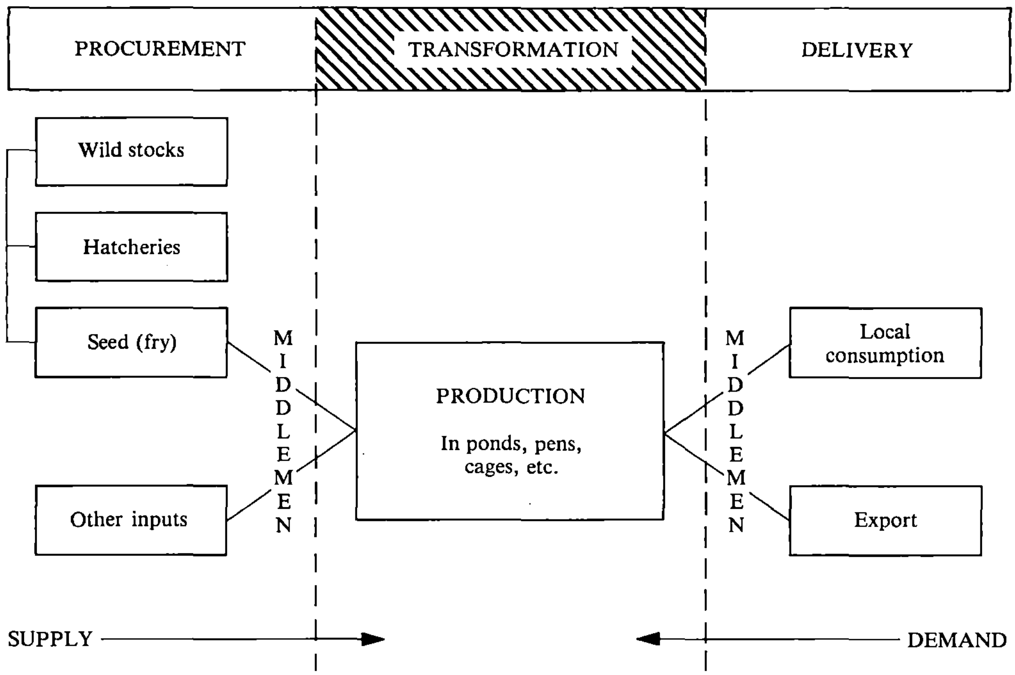


Fig. 1. A simplified aquaculture resource system.

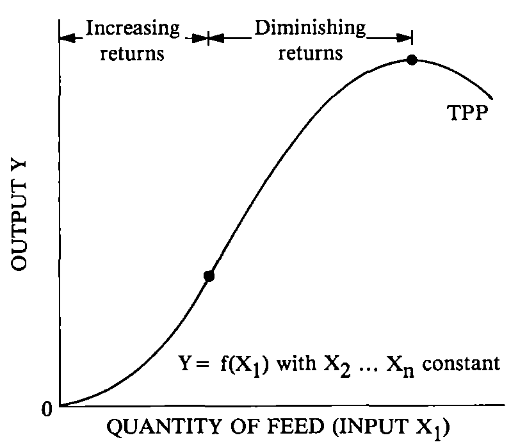


Fig. 2. Input/output with single variable input in short run (TPP = total physical product).

of input X_1 (e.g., feed) used. All other inputs have been held constant. As additional quantities of feed are applied, total physical product (TPP) as shown on the production response curve first increases at an increasing rate (increasing returns), then increases at a decreasing rate (diminishing returns), and finally, with excessive feeding, actually declines. This phenomenon of diminishing returns is best illustrated by the fact that if it did not exist, we could produce from a single small fishpond sufficient fish to feed the world. This single variable input case can also be expressed mathematically as:

$$Y = f(X_1) \text{ with } X_2 \ldots X_n \text{ constant}$$

where Y = output; X_1 = variable input; and $X_2 \ldots X_n$ are fixed inputs.

When two variable inputs (e.g., stocking rate and feed) are applied to the fishpond, we can represent the production response surface with a three-dimensional diagram (Fig. 3). This particular diagram shows diminishing returns over its full range. Three production isoquants, CC, DD, and EE, reflect the output attainable with various combinations of the two variable inputs. For example, 1000 kg of output can be attained with either high quantities of feed and low stocking rates or with lower quantities of feed and higher stocking rates. In other words, there is a certain degree of substitutability among inputs whereby output is not affected. This single output, two variable input case can be expressed mathematically as:

$$Y = f(X_1, X_2) \text{ with } X_3 \ldots X_n \text{ constant}$$

where Y = output; X_1, X_2 = variable inputs; and $X_3 \ldots X_n$ are fixed inputs.

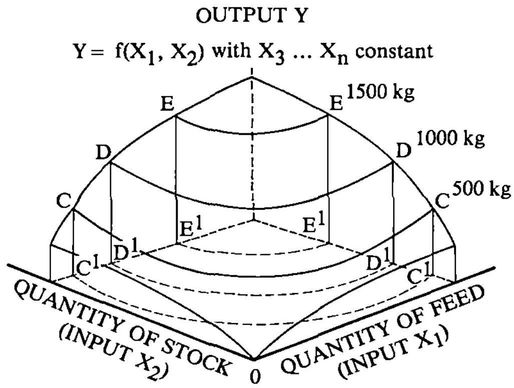


Fig. 3. Output as a function of two variable inputs (adapted from Hirshleifer 1976).

When three or more variable inputs are applied to the fishpond, it is no longer possible to depict the relationship between output and inputs using a diagram. Mathematically, however, we can express the relationship as:

$$Y = f(X_1, X_2, X_3 \ldots X_n)$$

where Y = output; and $X_1 \ldots X_n$ are variable inputs.

To this point we have been referring to output in terms of total physical product (TPP). The average physical product (APP) and the marginal physical product (MPP) curves, which are necessary to determine the rational range of input use and production for the aquaculture producer, can be derived from the production function. The relationships among these three curves are shown in Fig. 4. Point A is the point of diminishing returns (the inflection point) and thus the point at which MPP is at its maximum. Average physical product (APP) at this level of input application is, however, still increasing so it makes sense for the producer to increase the use of the variable input, at least to reach point B where APP is at its maximum. Point B thus defines the boundary between production area I and II, or the beginning of the area of rational economic production. With continued increase in use of the variable input, point C will eventually be reached where MPP reaches zero, and TPP begins to decline. Beyond this point is area III, an irrational area of production, because the same output can be achieved at lower levels of input use and cost. Area II is thus known as the area of rational economic production. To be able to determine the exact input level the producer should use, we need to introduce costs, returns, and profits to our theoretical model.

So far we have been referring to a purely biological or technical relationship. The production function per se is devoid of economic meaning, but it is the basic building block for the economic analysis to follow. Incorporation of the economic element can best be illustrated by an example (see Table 1).

Let us assume that we are dealing with a small production system with a 0.1 ha pond where fish (in kg) is the only output and where the single variable input is feed (in bags of 20 kg each). All other inputs (land, labour, stocking rate, etc.) are assumed to be fixed, bags of feed are available in unlimited quantity, and the producer has no capital constraint. Feed is assumed to have a constant cost (P_x) of \$8.00/bag, and the farmgate price (P_y) for fish is \$2.00/kg. We assume that the output price does not change in response to increases in output from our small producer. The small producer is a price taker in a competitive market. The question the fish farmer is trying to answer is: "How many bags of feed should I apply to maximize my profits from fish production?"

Maximum profits (\$40) are earned when five bags of feed are used. At lower levels of input use, the value of the marginal physical product (VMP or marginal revenue) obtained from each added input is greater than the marginal costs (P_x) of the added input. The marginal revenue from the sixth bag equals its marginal cost so the profit is unchanged. Beyond six bags of feed, the marginal

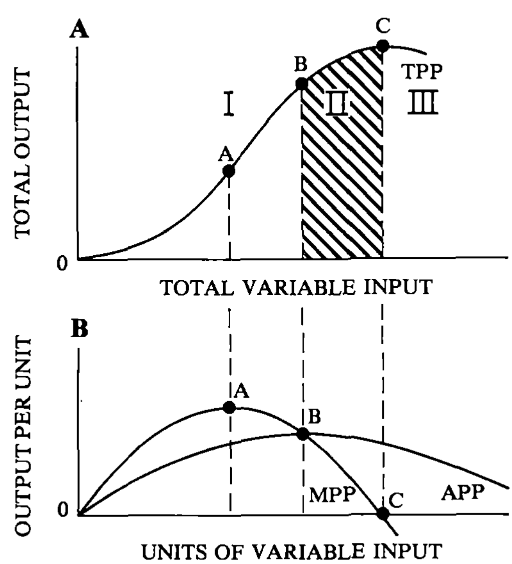


Fig. 4. The production function and some of its derivatives (from Snodgrass and Wallace 1970), where TPP = total physical product, APP = average physical product, and MPP = marginal physical product.

Table 1. Hypothetical data showing profit maximizing principle when inputs are unlimited.

Bags of feed	Total physical product (TPP)	Average physical product (APP)	Marginal physical product (MPP)	Value of the marginal physical product (VMP = MPP·P_y)	Marginal cost (P_x) ($)	Total revenue (TR) ($)	Total cost (TC) ($)	Profit (TR − TC) ($)
0	0	0				0	0	0
			6	12	8			
1	6	6				12	8	4
			7	14	8			
2	13	6.5				26	16	10
			(11)	22	8			
3	24	8				48	24	24
			10	20	8			
4	34	(8.5)				68	32	36
			6	12	8			
5	40	8				80	40	(40)
			4	8	8			
6	44	7.3				88	48	40
			1	2	8			
7	(45)	6.4				90	56	34
			−1	−2	8			
8	44	5.5				88	64	24
			−2	−4	8			
9	42	4.6				84	72	12

Note: Maximum values for TPP, APP, MPP, and profit are enclosed within parentheses. Adapted from a similar example in Snodgrass and Wallace (1970).

cost exceeds the marginal revenue. In other words, the producer should keep adding inputs as long as the additional revenue obtained exceeds the additional cost.

The same decision regarding optimal input use can be obtained graphically. Figure 5 illustrates this same example, and makes clear the relationship between the underlying production function and the economically determined level of optimum output and input use. Note that profits are maximized in the upper figure (a) when the difference between total revenue (TR) and total costs (TC) is at its maximum. As shown in the lower figure (b) this is achieved when the value of the marginal product (VMP) is equal to the input price (P_x), or the marginal cost of the added input.

Mathematically, this means that profits will be maximized when VMP = P_x and because VMP = MPP·P_y, one can determine the profit maximizing level of input use by equating the marginal physical product to the input/output price ratio: MPP = P_x/P_y.

There are several interrelated conclusions from this unconstrained case:

(1) *Maximizing production does not maximize profits.* In our example, maximum production is achieved with seven bags of feed, but profits are lower at $34 than the $40 obtained

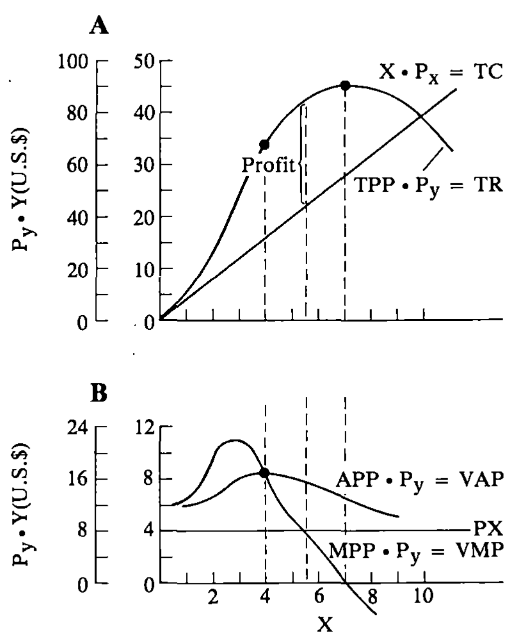


Fig. 5. Hypothetical revenue and cost curves (TPP = total physical product, APP = average physical product, MPP = marginal physical product, VAP = value of the average product, VMP = value of the marginal product, TC = total costs, and TR = total revenue).

from using only five bags of feed. Maximum profits are, therefore, obtained at lower levels of output and input use than those that maximize production.

(2) *The profit maximizing decision rule is based on marginal principles.* A producer who bases his production decisions upon average or total production and revenue principles will earn less profit than a producer who uses the marginal analysis described above.

(3) *The level of fixed costs does not influence the decision of the producer regarding optimal use of the variable input.* Note that the producer's decision is based upon a comparison of the marginal revenue and marginal cost of the variable input. Producers will continue to produce as long as they cover their variable costs.

The preceding example refers to an unconstrained case; that is where the producer has unlimited capital. In real life, of course, capital and other constraints usually do exist, and in the long run, producers have the option of using their limited resources for several alternative production processes. The marginal principle for maximizing profits, however, still applies. Fish farmers will maximize their profits if they use their limited resources (e.g., capital) in such a way that the marginal returns from the various activities are equal. In this way, the opportunity cost of their capital (i.e., the cost of the alternative foregone) does not exceed its value in the use chosen.

Production Functions: Estimation and Interpretation

The approach to production economics described in the preceding section is known as the neoclassical approach. First, the physical relationship between inputs and outputs is estimated, and then marginal analysis is employed to evaluate producer behaviour. It is assumed that the production function is continuous; that is, the marginal physical product can be derived from the production function through differential calculus. There are four distinct steps in the neoclassical approach: specification, data collection, estimation, and interpretation.

Specification

Specification of the model chosen to describe the production process depends in great measure upon the researcher's assumptions about the underlying biological relationships in the production process. Decisions must be made regarding: (1) which explanatory variables to include: and (2) the appropriate function form.

The underlying production process in aquaculture systems is not in fact a direct input to output relationship. In milkfish ponds, for example, output is only indirectly related to certain inputs, such as fertilizer, because output is a function of algae growth, which is in turn a function of the fertilizer applied to the pond. In this case, the correct production function would relate functions to functions rather than things to things (Garrod and Aslam 1977). Other inputs, however, such as seed stock and supplementary feed, are directly related to output. Because it is difficult to accurately and easily measure algae growth in milkfish ponds during a survey, the most common procedure is to assume a direct relationship between fertilizer and output. In this paper, we will deal only with production functions that directly relate various inputs (the explanatory variables) to output (the dependent variable). One of our purposes is to explain, as much as possible, the variation in output observed from farm to farm.

In biological experiments it is customary to hold all variables constant, except the one for which the biologist is interested in determining the effect on output. In the social laboratory in which economists operate, however, such controlled experimentation is not possible. With no variables controlled, the production function must be estimated from a host of explanatory variables.

For aquaculture production functions, we may wish to consider including some or all of the following inputs or explanatory variables: stocking rates; fertilizer; feed; pesticide; labour; land (or rearing area); environmental factors (soil pH, water salinity); management (expertise of operator); and dummy variables (e.g., for location). However, this is not an exhaustive list.

We can then develop hypotheses regarding the significance of each of these variables (and all of them taken together) in explaining variation in output. It is common practice to standardize the explanatory variables to account for differences in farm size. For example, the explanatory variables could all be expressed in terms of input quantity per hectare (for ponds) or per cubic metre (for cages). Each variable must be homogeneous; that is, fertilizers of various qualities should not be combined in a single variable. There is no fixed formula, however, to guide the researcher in the choice of explanatory variables for inclusion in the model being specified. Biologists should be consulted for their opinions so that in a priori fashion, the explanatory variables can be selected.

Dummy variables may also be included to account for differences (in location or climate for example) that cannot readily be quantified. A dummy variable takes the value of 1 or 0 depending upon whether the farm in question falls in the particular category or not. The presence of significant differences in output by climate type or location can then be tested for in a manner similar to that used for testing for the significance of the other quantifiable explanatory variables.

The management variable poses serious difficulties because it is hard to quantify the expertise of the aquaculture producer. One possible solution is to use a proxy variable, such as education level, as a measure of management expertise. Another solution is to treat the residual (the unexplained variation) after estimation of the production function as a measure of management. However, this is not entirely satisfactory because the residual or error term also includes the effects of all other variables not included in the model.

Once the researcher has chosen the relevant explanatory variables to include in the model, the next step is to specify the functional form to be used, that is, the form of the relationship between inputs and output. Four alternative functional forms are shown in Table 2. Of these four, the first two deserve only brief mention. The first, the linear form, is most commonly used in linear programing models and these are not discussed in this paper. The second form, the quadratic, shown as the special case where all but one explanatory variable are held constant, describes a parabola and is probably familiar to most biologists. The third and fourth functional forms, the Cobb-Douglas (C-D) and the constant

Table 2. Traditional forms of the production function.[a]

Linear

$$Y = A + \beta_1 X_1 + \beta_2 X_2 \ldots + \beta_n X_n$$

Quadratic (single input case)

$$Y = A + \beta_1 X_1 - \beta_2 (X_1)^2$$

Log-linear (Cobb-Douglas or C-D)

$$Y = A X_1^{\beta_1} X_2^{\beta_2} \ldots X_n^{\beta_n}$$

or

$$\log Y = \log A + \beta_1 \log X_1 + \beta_2 \log X_2 \ldots + \beta_n \log X_n$$

Constant elasticity of substitution (CES)

$$Y = \gamma[\delta X_1^{-p} + (1-\delta) X_2^{-p}]^{-\frac{1}{p}} \qquad (p > -1)$$

[a] Y = output; X_i = inputs; β_i = factor (input) productivities; and A, γ, δ, p are constants. Error terms are omitted.

elasticity of substitution (CES) functions, are those that have been traditionally favoured by production economists.

The C-D function, which is linear in its logarithmic form, has several advantages that have made it attractive. (1) The elasticities of production, which measure the responsiveness of output to increased units of input, are identical to the production coefficients (β_i). Consequently, a percentage change in output that is brought about by a given percentage change in input use can be easily determined. (2) The sum of the production coefficients ($\Sigma\beta_i$) can be interpreted as a measure of economies of scale.[2] If $\Sigma\beta_i > 1$, for example, positive economies of scale exist. This implies that a doubling of the use of all inputs will result in more than a doubling of output. (3) Unlike the linear and quadratic forms, which preordain the shape of the production surface, the unconstrained C-D form can describe a production surface that demonstrates increasing, unitary, or decreasing returns to scale, depending upon the data. (4) Input and output data can readily be used, without aggregation (as in the CES function) to estimate the parameters of the model. (5) Unlike the quadratic form, which uses up two degrees of freedom for each added variable, a C-D function that includes no interaction terms uses only one degree of freedom per explanatory variable.

The C-D production function is actually a special case of the CES function in that in the C-D function, the elasticity of substitution[3] among inputs is constrained to unity. In the CES function, the elasticity of substitution can be any constant value. Because this permits the empirical data to determine the degree of substitutability among inputs, some researchers (Miller et al., undated) have claimed that the CES production function is theoretically superior to the C-D formulation. In contrast, "in the C-D form, the relative input shares remain unchanged, even with a change in relative input prices and input ratios, because the elasticity of substitution between inputs is forced to unity" (Garrod and Aslam 1977, p. 21). Although the CES production function thus has some inherent theoretical advantages over the C-D, it is difficult to apply if

[2] Assuming that the $\Sigma\beta_i$ is not constrained to unity as in the original Cobb-Douglas case where

$$Y = A X_1^{\beta_1} X_2^{(1-\beta_1)}$$

[3] The elasticity of substitution shows the proportional change in the capital-labour ratio induced by a given proportional change in the input (factor) price ratio (Ferguson 1972).

more than two inputs are to be used. The usual technique is to aggregate all explanatory variables into the two inputs of capital (K) and labour (L).

The balance of the discussion in this paper is based upon the Cobb-Douglas production function.

Data Collection

The explanation of output variation through a production function requires that data be collected from a sufficiently large number of farms to allow reliable estimation of parameters. A minimum sample size of 30 is often established, so that adequate degrees of freedom are maintained.[4] Data on inputs, output, prices, and costs can be obtained from: (1) many aquaculture farms for a single production cycle; (2) one farm over numerous production cycles; or (3) many farms over time. These data types are, respectively: cross-sectional data; time-series data; and time-series of cross-sections (Garrod and Aslam 1977). The last of these data types is the most desirable, but due to costs of obtaining a time-series of cross-sections, it is rarely available. Most common at the current stage of aquaculture economics research is cross-sectional data gathered from a (sometimes) randomly chosen sample of producers. Because so few producers have records to share with the researchers, the two most common methods of data collection are recall questionnaires and record-keeping forms. The former method is particularly susceptible to measurement errors in quantifying the input used and output attained. Other measurement errors can also occur if the interviewer or the fish farmer fails to correctly delineate one input from another, say differences in quality of various supplementary feeds. The decision of what data type (time-series or cross-section) and collection methods to use is most often determined by the limited budgets available to researchers.

Estimation

Production functions are usually estimated using standard multiple regression techniques, in particular the ordinary least squares (OLS) method. The OLS method fits a line to the data by minimizing $\Sigma\ (Y_i - Y_e)^2$, the sum of the squares of the distances from the observed data points to the fitted line (Fig. 6).

An important distinction must be made between a "frontier" production function and the "average" production function that is estimated using the OLS method (Garrod and Aslam 1977). As shown in Fig. 7, the "frontier" production function is derived by connecting the points of maximum output for each level of input. It thus represents the most technically efficient input-output combinations. The estimated production function, on the other hand, is an industry "average" function because it is derived by OLS methods that take into account all observed input-output combinations, not only the most technically efficient. Consequently, the average production function, though describing the average aquaculture firm in the system, does not represent the maximum possible output obtainable from a set of inputs. To determine the maximum productive capacity of aquaculture systems, a frontier production function should be used.

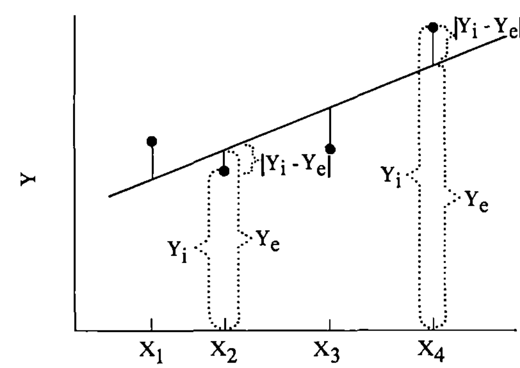


Fig. 6. Fitting a line using ordinary least squares (OLS) method (adapted from Alder and Roessler 1972).

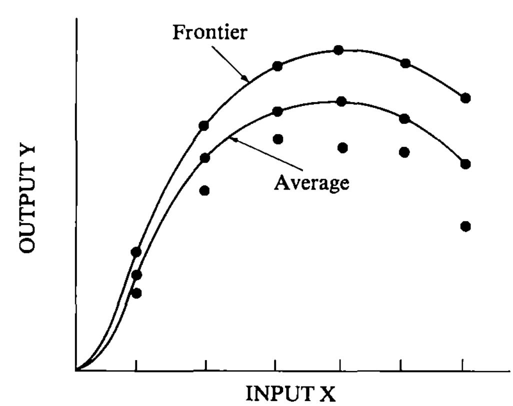


Fig. 7. Comparison between "frontier" and "average" production functions, single variable input case.

[4]Each additional explanatory variable included in the model reduces the degree of freedom by at least 1.

One specific estimation problem deserves particular mention. The problem of multicollinearity occurs when explanatory variables are highly correlated and produces biased estimates of the production parameters. Although some researchers (Rao and Miller 1971) claim that multicollinearity is more of a theoretical rather than an empirical problem, the applied researcher needs a decision-rule to decide if the degree of multicollinearity is serious enough to warrant discarding the specified model and starting again. One approach is to examine the simple correlations among the independent variables and eliminate from the model any that are highly linearly interrelated. A second approach is to plot the residuals (the difference between the observed Y_i and the estimated Y_e) against the independent variables to look for any systematic distribution of the deviations around the regression line. However, despite some success with these approaches, no hard-and-fast rule seems to have been devised to deal with the potential multicollinearity problem. Fortunately, with larger sample sizes, the multicollinearity problem is reduced (but not eliminated).

Before leaving the topic of estimation, mention should be made of step-wise regression. This is a technique for entering the independent variables into the model in order of their contribution to the "explained" variation in the dependent variable. In this fashion, the most important explanatory variables are included first, and the researcher can then drop out of the model those explanatory variables that are less important. This approach is generally not recommended unless the researcher is working with a small sample. Each dropped variable will increase the degrees of freedom, an important consideration when sample size is small (e.g., < 30).

Interpretation of Results

Before interpreting the results obtained from the estimated production function, it is necessary to examine the function for its ability to "explain" output variation. Two interrelated measures of "goodness of fit" are known as the correlation coefficient (R), and the coefficient of determination (R^2). The maximum possible value for R^2 is 1.0, which implies that 100% of the output variation is explained by the estimated function. In applied research using cross-sectional data, one would not expect to find such a high value for R^2. The F-test is usually used to test the overall significance of the independent variables chosen for inclusion in the model. The sign test can also be applied to determine if each of the production coefficients (β_i) has the expected positive or negative sign. Finally, t-tests are used to test the significance of the individual production coefficients.

Let us examine a hypothetical example of a C-D production function to interpret the results. A three input case is shown in Table 3. The variables are defined as follows, with mean values and prices as shown:

Variable	Mean value	Price ($)
X_1 = stocking rate (thousands/ha)	5	30.00
X_2 = feed (bags/ha)	6	25.00
X_3 = labour (man-days/ha)	9	2.00
Y = fish output (kg/ha)	367	2.00

The mean value for output (367 kg/ha) is calculated by substituting the mean input values into the production function and solving for Y.

In Table 3, the R^2 value is 0.8; therefore, 80% of the variation in output is explained by the three independent variables. All coefficients (β_i) have the expected positive sign. The coefficients of two of them (X_1 and X_2) are significantly different from zero at the 1% level according to the t-test.[5] The coefficient of the last input (X_3) is not significantly different from zero. The output or production elasticities are 0.3, 0.2, and 0.5, respectively. A 10% increase in input X_1, for instance, will produce a 3% increase in output, and so on. Because the sum of the coefficients equal 1.0, unitary economies of scale exist; a doubling of all three inputs will double output.

An important question yet to be answered is: "Are producers, on average, economically efficient?" In other words: "Is their use of inputs optimal in terms of maximizing their profits?" To answer this question it is necessary to calculate the marginal physical product of each of the variable inputs and compare it with the input-output price ratio:

$$MPP_{X_i} \gtreqless \frac{P_{X_i}}{P_y}$$

If MPP is greater than the price ratio, use of the input should be increased. If MPP is less than the price ratio, use of that input should be reduced. Equality implies producers, on average, are economically efficient. To calculate the MPP of each input from the production function, partial differentiation is used with all variables,

[5] H_o: $\beta_1 = 0$ and H_o: $\beta_2 = 0$ are rejected. H_o: $\beta_3 = 0$ is not rejected.

Table 3. Hypothetical Cobb-Douglas production function.[a]

$Y = 50X_1^{0.3}X_2^{0.2}X_3^{0.5}$		$R^2 = 0.80$; $F = 35.00^b$	
$\log Y = \log 50$			
$+ 0.3 \log X_1$	$+ 0.2 \log X_2$	$+ 0.5 \log X_3$	
s.e. (0.10)	(0.05)	(0.30)	
$t = \beta_i/\text{s.e.}$			
3.00^b	4.00^b	1.67	
Output elasticities			
0.3	0.2	0.5	
Economies of scale $= \Sigma\beta_i = 0.3 + 0.2 + 0.5 = 1.0$			

[a] X_1 = stocking rate; X_2 = feed; X_3 = labour; and Y = output.
[b] Significant at 1% level.

except the one being differentiated, entered into the production function at their geometric mean.

In the example of Table 3, the MPP of input X_1, for example, would be calculated as follows:

$$\begin{aligned} Y &= 50\, X_1^{0.3}\, X_2^{0.2}\, X_3^{0.5} \\ \partial Y/\partial X_1 &= 50(0.3)X_1^{-0.7}\, X_2^{0.2}\, X_3^{0.5} \\ &= 50(0.3)\,(5)^{-0.7}\,(6)^{0.2}\,(9)^{0.5} \\ &= 50(0.3)\,(0.32)\,(1.43)\,(3.0) \\ &= 20.59 = \text{MPP of input } X_1 \end{aligned}$$

$$\text{The price ratio } P_{X_1} / P_y = \frac{30.00}{2.00} = 15$$

Because MPP $> P_{X_1} / P_y$ (e.g., $20.59 > 15$), the use of input X_1 on the "average" farm should be increased. This can also be concluded from the fact that the value of the marginal product (VMP $=$ MPP$\cdot P_y$ $=$ \$41.18) is greater than the marginal cost (P_{X_1} = \$30.00) of the additional unit of input. Marginal physical products for the other two inputs would be calculated in a similar manner, and their use either increased or decreased depending upon the relationship between the MPP and the respective price ratio.

The preceding discussion has focused on the Cobb-Douglas production function and its interpretation. There are numerous other functional forms that can be used to analyze production, costs, and profits. As in agricultural economics, these somewhat more sophisticated approaches will undoubtedly find favour with aquaculture economists in the years to come.

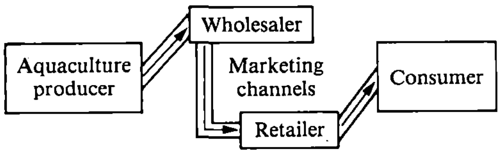
Marketing Subsystems

Brief mention should be made also of some basic aquaculture marketing concepts. Just as in production economics, there are numerous alternative approaches to analyzing marketing or delivery subsystems. Four major approaches are known as: (1) functional approach; (2) institutional approach; (3) organizational approach; and (4) price-efficiency approach.[6] The functional approach examines the important marketing functions of exchange (buying and selling), physical handling (storage, transportation, and processing), and facilitation (standardization, financing, risk bearing, market intelligence). The institutional approach studies the various agencies and intermediaries that perform the marketing process. Both of these approaches are essentially descriptive. The organizational approach attempts to link the structure of the market (concentration ratios, barriers to entry, product differentiation) to the conduct of intermediaries (price determination and competition) and the performance of the subsystem (profit margins, technical efficiency, progressiveness). This approach has most often been used in comparisons among various industrial marketing systems. Finally, the price-efficiency approach examines the role of prices and their allocative functions in terms of space, time, and form.

It is useful to mention the major principles and definitions. In Fig. 8 a very simple marketing or delivery subsystem is shown. The output from aquaculture producers moves through marketing channels, representing product flows, first to wholesalers, then to retailers, and finally to consumers.

The prevailing price at the farmgate (P_f) is related to the consumer price (P_c) by the marketing costs of intermediaries. Under conditions of perfect competition, the difference between the consumer and farmgate prices, known as the marketing margin, should over time on average equal the sum of all the marketing costs involved. Marketing costs include not only direct costs but also implicit costs, such as opportunity costs of the marketing inputs and a reasonable return to marketing intermediaries for their risk and management expertise. Arbitrage among various trading regions should keep the marketing costs roughly equal to the price differential as long as conditions approximating perfect competition (freedom of entry and exit, perfect information about supply and demand) exist. Analysis of marketing subsystems frequently focuses upon assessing departures from the norms of perfect competition.

[6]For discussion of the first and second see Kohls and Downey (1972); of the third see Bain (1968); and of the fourth see Bressler and King (1970).



$$P_f + \text{Marketing costs of middleman} = P_c$$

$$P_c - P_f = \text{Markup/Margin}$$

Fig. 8. Basic marketing concepts. Under perfect competition, differential between farmgate price (P_f) and the retail price (P_c) should equal the marketing costs of all middlemen, including a reasonable profit.

Conclusion

The production economics methodologies outlined in the preceding sections lead to conclusions that are primarily of interest to the policymaker. It would be unwise for a researcher to use the estimated production function to advise an individual farmer on optimum input levels because what is needed is location-specific advice. More than just ecological differences (soil, climate, etc.) are involved. A technology package may make sense in one area where input/output prices reveal marginal returns greater than marginal costs; in another area where the prevailing input/output prices are different, profits of producers may even be lowered by adopting the new technology. It is these location-specific differences that make technology packaging so very difficult and adaptation to locally prevailing conditions so expensive. However, progress can be made if biologists can determine the production response of different technologies and economists can evaluate the effect on producer profits. The need for this kind of teamwork is a strong argument in favour of interdisciplinary approaches to aquaculture research and development.

Analyses of existing aquaculture systems help us to understand the technical and socioeconomic environment in which producers operate and into which improved technologies are to be introduced. Depending upon the stratification of the sample, important differences between groups of producers can also be identified. Moreover, if through a production economics study, a group of existing producers are shown to be economically efficient, given the prevailing prices, it is hardly surprising that they do not adopt a new, allegedly superior technology. Production economics studies may then force us to discard our often held view that producers are somehow "irrational."

In the introduction to this paper, it was stated that producers respond to relative economics of various production alternatives, given their available resources. A production economics study of a specific aquaculture system is only the first step in revealing these relative economics and the producers' response. What are needed are similar studies of the alternative systems (for other aquaculture species, for example) or even of alternative use of the land (for grain production, for example).

Aquaculture economists are following in the footsteps of agricultural economists who have faced many of the same questions regarding efficiency, optimum farm size, and technology transfer that we are currently grappling with. It would not be inaccurate to characterize current aquaculture economics work as experimental in that we are still testing methodologies that have been used extensively in agriculture. Further refinements, particularly along the lines of cost and perhaps profit functions, and whole systems analysis would be very worthwhile undertakings. It would be unfortunate if we do not relate our efforts to the experience and insights of those who have gone before. The writings of Theodore W. Schultz, distinguished agricultural economist and Nobel prize winner, should be required reading for everyone interested in technological change. (See, for example, Schultz 1966.)

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The Economics of Aquaculture: The Case of Catfish in Thailand

Sarun Wattanutchariya and Theodore Panayotou[1]

After a brief introduction to catfish culture in Thailand, this paper deals with cost structure, profitability, and production technology. The emphasis is on the dominance of feed, and particularly trash fish, in the cost structure and the profit differential between small and large farms as well as between inexperienced and experienced farmers. It is concluded that there is inefficiency in input use (too much fry and trash fish and too little broken rice and fuel used) and recommended that more credit be given to small farmers and that research and extension be intensified to determine optimum feed formulas and ways to control disease.

Commercial fish culture, induced by high fish prices and the decline of fish availability from natural sources, has developed in Thailand only during the past few decades. The expansion of fish culture was supported by the improvement of the irrigation system that provides water for the paddy land in the Central Region. The species commonly raised are catfish (*Clarias* spp.), striped catfish (*Pangasius sutchi*), sepat siam (*Trichogaster pectoralis*), snakehead (*Ophiocephalus striatius*), carps, tilapia, and giant prawn (*Macrobrachium rosenbergii*). Among these species, catfish have been particularly popular, partly because of high price and partly because of their short culture cycle.

The expansion of catfish culture, however, has its limitations. In Suphan Buri province, the largest catfish farming area of the country, the number of farms, which had increased from 45 farms with a total area of 16 506 m^2 in 1967 to 468 farms with a total area of 495 646 m^2 in 1973, dropped to 76 farms with a total area of 345 788 m^2 in 1976. The decline in both the number of farms and the pond area was due to losses resulting from catfish disease, a drop in catfish prices, and the rising price of inputs, especially trash fish, a major feed ingredient. For the country as a whole, the Department of Fisheries reported a drop in total production of 40 262 t valued at 5798 million baht in 1973 to 19 714 t valued at 315 million baht in 1976 (22.60 baht = U.S.$1.00). This decline in production caused an increase in catfish prices and should have induced a rise in the supply of catfish. However, this did not occur; the number of catfish farms continued to decline.

Therefore, a careful investigation of the economics of catfish culture would benefit both producers and policymakers. Previous studies on the economics of catfish culture were based on too small, nonrandom, samples that were not representative of catfish culture in the country. Moreover, none of the studies attempted to estimate the parameters of production technology or examine the degree of efficiency in input use.

The specific objectives of this study were: (1) to estimate the technological coefficients of catfish production; (2) to determine the returns to scale; (3) to find the optimum input use under alternative behavioural and market assumptions; and (4) to determine the profitability of catfish farming by farm size and experience.

Most catfish farms are located in the Central Region of Thailand and the two provinces, Suphan Buri and Nakhon Nayok, were chosen to represent catfish culture in the Central Region. It was found that more than 50% of the catfish farms in each province were in a few districts. Random selections were made of 23 farms in Suphan Buri and 18 farms in Nakhon Nayok. The 41 farms, almost 80% of the farms in each district, constitute a fair representation of catfish farming in the Central Region but do not necessarily represent other regions due to different cost structures and cultural practices.

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The main occupation of most farmers in the study areas is rice farming. Catfish culture has undoubtedly developed from paddy fields close to the irrigated canals. There are some farmers who rent land and turn it into catfish ponds. It was found that 78% of the farm sample in Suphan Buri raised catfish as their main occupation compared with only 22% in Nakhon Nayok. Between the two study areas, there is a remarkable difference in the cultural system: catfish culture in Suphan Buri can be considered as intensive farming; in Nakhon Nayok extensive farming is practiced. The average pond size in Suphan Buri is 2290 m^2 compared with 3129 m^2 in Nakhon Nayok.

Experience in catfish culture was hypothesized to be one of the factors influencing profitability. Farmers in Suphan Buri had a longer history of catfish culture, 6.9 years on the average, whereas most farmers in Nakhon Nayok had only 2.9 years of experience. The test of the significance of experience as a determinant of profitability will be presented later. There was no difference in the average age and education of farm owners in the two areas. Most farmers were between 30 and 50 years of age and had 4 years of school education. Therefore, age and education cannot be used to explain differences in managerial ability.

Catfish Cultural Practices

The two catfish species raised in Thailand are *Clarias batrachus* and *C. macrocephalus* and both are found in natural sources of water. However, when cultured in a pond, *C. batrachus* grows much faster than *C. macrocephalus*. Besides, its fry can be obtained from a hatchery whereas fry of *C. macrocephalus* must be obtained from natural sources. All the sampled farms in this study cultured *C. batrachus*.

Catfish fry used to be collected from natural water sources during May and October. But, fry producers now provide fry from late January to November, which enables catfish farmers to raise catfish throughout the year.

Pond Construction and Preparation

Culturing of catfish starts with the construction and preparation of the pond, which is dug either by hand or with a bulldozer to a depth of 1.5–2 m. Farmers preferred using bulldozers to make the border and dikes more compact and prevent leakage. In some cases, especially in Suphan Buri, pond banks were lined with bricks and stones to reduce erosion caused by the fish. Pond preparation involves the drying of the pond after draining. In many cases, farmers also apply lime at the rate of 30–60 kg/rai (185–375 kg/ha) to eliminate predators and other undesirable fauna and to reduce the acidity of soil and water.

Seed Procurement and Stocking

Stocking is done after the water is left in the pond for a few days. The depth of the water should be about 50–80 cm. Fry and fingerlings are raised mainly in Cha-Chueng Sao province, which is the only area where hatchery operations have been generally successful. Fingerlings are transported by truck to the fish farms, and mortality due to transportation is about 5%. No farm in the survey reported having nursery ponds; therefore, the fingerlings are stocked directly into the rearing pond. Stocking rate varies from farm to farm. According to the Department of Fisheries, the recommended stocking rate for 3–5 cm fingerlings is 60–100 fingerlings per square metre. However, the farmers stock between 45 and 400 3–8 cm fingerlings per square metre. The average stocking rate is 130 fingerlings per square metre. The reason given for the high stocking rate was high mortality of fingerlings due to many diseases. Farmers in Suphan Buri stocked more than twice as many fingerlings as farmers in Nakhon Nayok (Table 1).

Feeding Practices and Problems

The most important component of catfish feed is trash fish obtained from trawl fisheries, mainly those in Samut Sakhon province. Trash fish used to be a low-priced feed during the early 1970s, but due to a rapid increase in demand for other uses such as fish meal and duck farming, the price of trash fish has been increasing at a remarkable rate: from 1.50 baht/kg in 1973 to 2.50 baht in 1979 to 3.40 baht in early 1981. This increase has forced some small farms with no access to credit to go out of business. Some farmers did try using artificial feed, but at the time of the survey, farmers had a negative attitude toward artificial feed because of its high cost and the slow growth of catfish when compared with the use of trash fish. However, if the price of trash fish increases further, artificial feed may become more common.

The feed-mix varies during the rearing period. For the first 2 weeks, the fingerlings are fed on ground trash fish, sometimes mixed with rice bran to form a "sticky" mixture. As the fish grow, boiled broken rice is added to the feed. The proportions of feed differ between the two locations. Due to higher stocking rate farmers in

Table 1. Average yield and input use by location in 40 catfish farms in Suphan Buri and Nakhon Nayok, 1979.

	Suphan Buri	Nakhon Nayok
Sample size (farms)	22	18
Average farm size (m² of pond area)	2361	3125
Average yield (kg/m²)	9.56	4.06
Stocking rate (fingerlings/m²)	188.00	76.00
Feeding rate (kg/m²)	51.17	17.17
Feed/stocking ratio (kg/fingerling)	0.27	0.23
Feed mix		
Trash fish (% by weight)	77.87	62.12
Rice bran (% by weight)	14.17	17.84
Broken rice (% by weight)	7.96	20.04
Artificial feed (baht/m²)	0.33	0.28
Conversion ratio (feed/yield)	5.35	4.23
Survival rate (%)	33.61	49.45
Medicine (baht/m²)	2.96	0.38
Fuel use		
(L/m²)	0.35	0.77
(L/100 fingerlings)	0.14	1.01
(L/100 kg feed)	0.68	4.47
Family labour (man-hours/m²)	0.27	0.11
Pond investment (baht/m²)	5.53	5.18
Investment in facilities (baht/m²)	25.35	9.22
Culture period (months)	4.09	3.58
Cropping intensity (crops/year)	1.36	1.44
Farmers' experience (years)	6.90	2.90

Suphan Buri use a higher percentage of trash fish in the feed. The average proportion in Suphan Buri is 10 parts of trash fish, 2 parts of rice bran, and 1 part of boiled broken rice weight; in Nakhon Nayok the proportion is 3:1:1 (Table 1).

The feeding rate reveals the technical ability of the owner. Too much feed not only increases production cost but also pollutes the water and causes diseases. Too little feed causes starvation and slow growth. Most farmers feed their fish twice a day, once in the morning and once in the afternoon. The feeding rate is determined by observing feed consumption: when only a small number of fish come to the surface to eat the feed, it is judged that a sufficient amount has been given.

Diseases and Treatment

Disease is the most important problem in catfish farming and has caused the bankruptcy of many farms. Diseases are considerably more common than in the case of other species partly due to the high density of fish and partly due to the poor quality of water, which was polluted by decayed trash fish. Moreover, diseases are transmitted by infected fingerlings and carried from farm to farm through the common water source.

The diseases most commonly found in both locations were lesions, swelling of the area near the pectoral fin, and abdominal dropsy. About 80% of the sampled farmers reported the use of some medicine mixed with feed such as Terramycin (oxytetracycline) in the case of diseases and formalin in the case of parasites. More than 50% of the farmers expressed satisfaction with the treatment despite its high cost.

Harvest and Market Outlet

Harvesting starts after 3–4 months of cultivation. The marketable size for catfish is 20–25 cm in length and 200–250 g in weight. Although consumers prefer medium-size fish, when the price of fish is relatively low, farmers may delay their harvest up to 6 months. This prolongation or delay of harvesting time, however, is constrained by the cost of additional feed, foregone interest, the probability of disease, and possible delay of the next crop. Generally, most farmers, except the few with large farms and high capital investment, are unable to delay or prolong their harvest.

Harvesting is by draining water from the pond or by using a net. Usually buyers are responsible for harvest labour and for transport of the fish to market. Most sampled farms harvest only once per pond, but very large ponds may require more than one harvest. There are a variety of market outlets ranging from local trash fish suppliers, to wholesalers, to the Fish Market Organization in Bangkok. On average, one-third of the fish is sold to the trash fish suppliers, who in some cases have provided credit to the farmers. The Fish Market Organization and wholesalers from Bangkok shared another third of the produce, and the rest went to wholesalers from other provinces who caught and transported the fish to the northern and northeastern regions of the country.

Although there are only a few buyers in each area, 78% of the farmers reported no sales obligations. The other 22% bought feed supplies on credit. However, there was no significant difference in prices among buyers.

Credit

Catfish culture is a capital intensive investment, and more than 50% of the farmers had borrowed money for their operations. Among the indebted farmers, 50% received loans from the bank at an interest rate of 12–15% per year. Borrowers from other sources, such as trash fish suppliers, had to pay higher rates. Some farmers said they were seeking credit but they were unable to obtain any.

Input Use and Yield[2]

Input use and yield per unit of land (square metre) are given in Table 1. The most important input is feed. As mentioned earlier, Suphan Buri farmers practice intensive culture: they used 51.17 kg of feed per square metre compared with 17.17 kg used by Nakhon Nayok farmers. The use of other inputs such as medicine and family labour was also higher in Suphan Buri. Because of the better water circulation system in Suphan Buri, less fuel was used for water changes than in Nakhon Nayok. Farmers in Suphan Buri used more inputs (especially fingerlings and feed) per square metre and their average yield was more than double that in Nakhon Nayok (Table 1).

The use of inputs and yield per square metre may not be very meaningful because they depend on culture period, which was longer in Suphan Buri. A study of costs and profitability will help clarify the difference between intensive and extensive culture.

Cost Structure

Costs have been classified into three components: (1) variable cash costs, i.e., expenses that are actually paid and vary with the quantity of fish produced, such as fingerlings, feed, hired labour, and medicine; (2) fixed costs, which are independent of the operation, such as depreciation of ponds and facilities; and (3) imputed opportunity costs of owned inputs, which may be either fixed or variable, such as family labour, land use, and interest on fixed capital.

There was little difference in cost structure between the two locations. Variable cost accounted for more than 93% of the total cost and the rest was divided between fixed and imputed cost. Among the variable costs, the cost of feed dominated all other costs accounting for 71.2% of the total cost. Trash fish, the most important component of feed, accounted for more than 52% of the total cost on average. The cost of fingerlings came second at 11.4% of total cost.

[2]Henceforth, the sample includes only 40 farms. One farm was dropped because the input and cost data given were incomplete for cost and production analysis.

Costs in absolute terms, both per square metre and per kilogram, are presented in Table 2. The total cost per square metre in Suphan Buri was more than double that in Nakhon Nayok. However, the cost per unit of output for farmers in Suphan Buri was only slightly higher, 16.66 baht/kg compared with 14.59 baht/kg in Nakhon Nayok. Therefore, it is cheaper to produce a kilogram of fish by extensive farming.

Profitability

Despite higher cost per kilogram, farmers in Suphan Buri made more total profit than farmers in Nakhon Nayok because of higher yield. Table 2 summarizes the profitability of catfish farming per square metre in both locations. Alternative concepts of profitability are employed: (1) operating profit, defined as gross revenue minus variable costs; (2) net income or return to owned factors of production, defined as operating profit minus fixed cost; and (3) net profit or return to management, defined as gross revenue minus total cost. Profitability per kilogram of fish in Nakhon Nayok was higher than in Suphan Buri in terms of all indications. Nevertheless, the net profit per unit of land was higher in Suphan Buri: 26.50 baht/m^2 compared with 20.72 baht/m^2 in Nakhon Nayok. This was expected because of the higher intensity of culture in Suphan Buri, i.e., more investment in fixed and operating capital per square metre than in Nakhon Nayok. In terms of total profitability per farm, both operating profit and net farm income in Suphan Buri were higher than in the extensive farms of Nakhon Nayok. However, net profit, which is the net of the opportunity costs of owned factors of production, was lower in Suphan Buri because of the large capital investment. The average net profit per farm in Suphan Buri and Nakhon Nayok was 62 567 baht and 64 750 baht, respectively. Rate of return to capital investment and rate of return to total investment of Suphan Buri farmers were much lower than those in Nakhon Nayok (Table 3).

In conclusion, extensive culture, although having a lower return per unit of land, can produce catfish at the least cost. Therefore, extensive culture should be preferable especially by Thai farmers who have little capital of their own and limited access to credit. Given the country's and the farmers' factor endowments, the average farmer should choose extensive culture with lower capital investment and less risk.

Table 2. Cost, revenue, and returns (baht) per square metre of pond area and per kilogram of fish in 40 catfish farms in Suphan Buri and Nakhon Nayok, 1979 (22.60 baht = U.S.$1.00).

	Per square metre pond area		Per kilogram of fish	
	Suphan Buri	Nakhon Nayok	Suphan Buri	Nakhon Nayok
Variable costs (V)				
Fingerlings	17.69	7.08	1.85	1.74
Feed	116.67	39.06	12.21	9.62
Fuel and electricity	2.61	2.69	0.27	0.66
Hired labour	1.65	1.27	0.17	0.31
Medicine, chemicals, etc.	3.15	0.42	0.30	0.12
Maintenance[a]	0.74	0.51	0.08	0.13
Interest on operating capital	7.13	2.56	0.75	0.63
Total	149.64	53.65	15.66	13.21
(Standard deviation)	(94.69)	(60.08)	(17.19)	(7.60)
Fixed costs (F)				
Depreciation of pond	0.55	0.26	0.06	0.06
Depreciation of facilities[b]	2.53	1.99	0.27	0.49
Interest on debt	1.06	0.88	0.11	0.22
Total	4.14	3.13	0.44	0.77
(Standard deviation)	(4.75)	(7.72)	(0.95)	(4.07)
Owned inputs (opp. costs)				
Family labour (V^1)	0.66	0.47	0.07	0.12
Interest on fixed capital (F^1)	2.25	0.88	0.24	0.22
Land use (F^1)	2.32	1.08	0.25	0.27
Total	5.23	2.43	0.56	0.61
(Standard deviation)	(6.1)	(4.4)	(1.3)	(7.1)
Total costs	159.01	59.21	16.66	14.59
(Standard deviation)	(100.6)	(63.7)	(18.5)	(7.4)
Gross revenues	185.51	79.93	19.41	19.69
(Standard deviation)	(120.2)	(72.0)	(3.7)	(3.2)
Returns				
Operating profit[c]	35.87	26.28	3.75	6.48
Net income[d]	31.73	23.15	3.31	5.71
Return to land, capital, and management	31.07	22.68	3.24	5.59
Return to capital and management	28.75	21.60	3.00	5.32
Net profit[e]	26.50	20.72	2.75	5.10
(Standard deviation)	(99.0)	(35.8)	(19.4)	(17.6)

[a]Includes only maintenance of buildings, machinery, and equipment, pond maintenance consisted mainly of labour costs.
[b]Facilities include buildings, machinery, and equipment.
[c]Operating profit = gross revenue – variable costs (V).
[d]Net income = return to owned inputs = operating profit – fixed costs (F).
[e]Net profit = return to management = gross revenues – total costs.
Note: V and F refer respectively to variable and fixed costs that cannot be regarded as income to be consumed without impairing future operations. V^1 and F^1, on the other hand, refer, respectively, to variable and fixed costs that consist of payments to own factors of production and, hence, constitute net family income.

Role of Farm Size

The size of farm was hypothesized to play an important role in farm success because it reflects availability of capital, access to credit, and even managerial ability. The sampled farms were classified into small (1000 m^2 and less), medium (between 1001 and 3000 m^2) and large (over 3001 m^2). There were 12 small, 15 medium, and 13 large farms. Yield, total revenue, costs, and rate of return for farms in both locations are reported in Table 4. The highest average yield (almost 11 kg/m^2) was obtained by large farms under intensive culture in Suphan Buri. Under the extensive culture the small farms obtained the

Table 3. Rates of return (%) per farm in Suphan Buri and Nakhon Nayok, 1979.

	Suphan Buri	Nakhon Nayok
Rate of return to CI[a]	93.0	150.0
Rate of return to TI[b]	74.19	102.1
Ratio of net profits to variable costs	17.7	38.6
Ratio of net profit to gross revenues	14.3	26.1

[a]Rate of return to capital investment (CI) = (return to capital and management/capital investment) × 100.
[b]Rate of return to total investment (TI) = (return to land, capital, and management/total investment) × 100.

highest yield (7 kg/m^2). Higher yield was obtained by more intensive use of inputs and, therefore, higher cost per unit. The net profits of both small and medium farms in both locations were negative, whereas large farms showed a net profit of 230 236 baht per farm in Suphan Buri and 201 021 baht in Nakhon Nayok. Thus, large farms are considerably more profitable than small and medium farms; in fact, the latter are not economically viable under the present conditions.

Role of Experience

Experience was thought to be a determinant of profitability in catfish culture because experience would allow farmers to adjust to changing economic conditions and adopt the most efficient cultural practice. Farmers in both locations were classified into groups based on their years of experience in catfish culture. Experienced farmers were defined as those with more than average experience; inexperienced farmers were those with less than average experience. The average experience was 6.9 years in Suphan Buri and 2.9 years in Nakhon Nayok. This method of classification allows comparison within each location but not between locations.

Yield, costs, and profitability classified by experience are shown in Table 5. The average yield per square metre of the experienced farmers in Suphan Buri was almost double that of the inexperienced farmers, and in Nakhon Nayok it was more than three times as much. Experienced farmers in both Suphan Buri and Nakhon Nayok showed significantly higher net total profit than the inexperienced farmers. Because there was little difference in the use of inputs between experienced and inexperienced farmers, managerial ability due to experience in catfish culture could be the determinant of the difference in profitability regardless of type of culture.

The implication of this finding is that a certain scale of operation and level of knowledge are required for a successful operation. Large farmers, in general, are more specialized and have more advantage in terms of access to capital, credit, and technical knowledge, whereas, many small farmers, who take catfish

Table 4. Summary of yield, revenue, costs, and rates of return for different size farms in Suphan Buri and Nakhon Nayok, 1979.

	Suphan Buri			Nakhon Nayok		
	Small[a]	Medium	Large	Small	Medium	Large
Average yield (kg/m^2)	7.07	6.79	10.91	7.06	2.42	4.30
Gross revenue (baht)	84717	190374	1074370	82950	68281	600494
Total costs	103778	203107	843985	85891	71866	399474
Operating profit[b]	-11480	3640	273464	8664	7940	229941
Net profit[c]	-19062	-12733	230236	-2941	-3585	201021
Rates of return (%)						
Rate of return to CI[d]	-123.1	-8.9	-144.6	-8.2	-5.2	239.9
Rate of return to TI[e]	-81.6	-14.6	-110.6	-5.0	-1.9	151.2
Ratio of net profit to variable costs	-19.8	-6.8	-28.1	-4.0	-6.0	54.2
Ratio of net profit to gross revenues	-22.5	-6.7	21.4	-3.5	-5.2	33.4

[a]Small, less than 1000 m^2; medium between 1001 and 3000 m^2; large more than 3001 m^2.
[b]Operating profit = gross revenue – variable costs.
[c]Net profit = return to management = gross revenue – total costs.
[d]Rate of return to capital investment = (return to capital and management/capital investment) × 100.
[e]Rate of return to total investment = (return to land, capital, and management/total investment) × 100.

Table 5. Summary of yield, revenue, costs, and rates of return for different amount of experience of farmers in Suphan Buri and Nakhon Nayok, 1979.

	Suphan Buri		Nakhon Nayok	
	Inexperienced[a]	Experienced	Inexperienced	Experienced
Average yield per m^2	7.41	13.25	1.54	5.43
Gross revenues (baht)	424846	453767	52986	495822
Total costs	413346	329667	62365	338334
Operating profit[b]	38140	140573	4363	179388
Net profit[c]	11382	124100	-9380	157488
Rates of return (%)				
Rate of return to CI[d]	19.1	320.0	-16.6	286.5
Rate of return to TI[e]	17.2	208.2	-10.8	178.0
Ratio of net profit to variable costs	2.9	39.6	-19.3	49.8
Ratio of net profit to gross revenues	2.7	27.3	-17.7	31.8

[a]Inexperienced, farmer with less than average experience; experienced, farmer with more than average experience; average experience was 6.9 years in Suphan Buri and 2.9 years in Nakhon Nayok.
[b]Operating profit = gross revenue - variable costs.
[c]Net profit return to management = gross revenue - total costs.
[d]Rate of return to capital investment = (return to capital and management/capital investment) × 100.
[e]Rate of return to total investment = (return to land, capital, and management/total investment) × 100.

culture as a minor occupation, have little access to credit, insufficient funds, and the inability to take risks. The availability of funds or credit and technical knowledge and skill hold the key to successful catfish culture in Thailand.

Production Technology and Efficiency

While cost and return analysis measures the success and failure of farm business, the estimation of the production function identifies inputs that influence product yield and shows the efficiency of input use and the returns to scale.

A Cobb-Douglas production function was employed to estimate the production technology of catfish farming input and output data of 40 farms. The production function used can be expressed in the following general form: $y = f(x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8)$, where y = yield in kg/m²; x_1 = number of fingerlings stocked/m²; x_2 = quantity of trash fish used in kg/m²; x_3 = quantity of broken rice used in kg/m²; x_4 = quantity of rice bran in kg/m²; x_5 = amount of fuel in kg/m²; x_6 = chemical and medical treatment in baht/m²; x_7 = labour in man-days/m²; and x_8 = fixed capital investment (excluding land) in baht/m².

Because farm size, experience, and location are also important in determining yield, dummy variables (D_1, D_2, D_3, D_4) were also included such that: $D_1 = 1$ if farm is small ($\leqslant$ 1000 m^2) and equals 0 otherwise; $D_2 = 1$ if farm is large ($>$ 3000 m^2) and equals 0 otherwise; $D_3 = 1$ if farmer has more than the average experience (6.9 for Suphan Buri and 2.9 for Nakhon Nayok) and equals 0 otherwise; and $D_4 = 1$ if farm is located in Nakhon Nayok and equals 0 if farm is located in Suphan Buri.

Ordinary least squares methods were used to estimate four different regression models. Of the eight explanatory variables in model R1 only four, fingerlings (x_1), trash fish (x_2), fuel (x_5), and family labour (x_7), were statistically significant at the 0.05 confidence level. This model could explain 70% of the variation in yield. Fingerlings was the most powerful explanatory variable with the highest partial output elasticity (0.484), which indicates that a 10% increase in the stocking rate, holding other inputs constant, will increase yield by 4.84%. The sum of all partial output elasticities was 0.897, which indicates diminishing returns to scale.

Dummy variables representing farm size and experience were added in model R2. Both these dummy variables were significant at the 0.05 level of confidence. This model indicates that there were differences in productivity between large farms and small or medium farms and between experienced and inexperienced farmers. Treatment (x_6) was added to model R3 and was found to be highly significant. Finally, model R4 with a dummy variable for location could explain 81% of yield variation, although variables significant in other models turned out to be insignificant and returns to scale changed from diminishing to constant.

To study price efficiency, the marginal physical products of the four main inputs, fingerlings, trash fish, broken rice, and fuel were calculated as follows: $MPP_i = b_i (y/x_i)$, where MPP_i = marginal physical product of input i; b_i = partial elasticity of production of input i; y = estimated output at geometric mean of all inputs; and x_i = geometric mean of input i.

Efficiency in input use requires that each input is used at such a level that the value of its marginal product is equal to its price, or $VMP_i = P_y MPP_i = P_i$, where P_y is the price of output, or $(VMP_i/P_i) = 1$. If the value of the marginal product of an input is greater than its price, profit could be increased by increasing the use of that input. The results of these calculations are shown in Table 6. All four variables investigated were used inefficiently: the number of fingerlings and quantity of trash fish used should be decreased and the use of fuel for water change and of broken rice should be increased.

Summary and Policy Implications

Catfish culture in Thailand was initiated by the farmers with minimum support from the government. The expansion of catfish culture was dramatic in the late 1960s and early 1970s but in recent years it has been retarded by the spread of catfish diseases and the escalation of input prices, especially trash fish, which accounts for over 50% of the total cost of production. Many catfish farmers have been forced to switch to other species or crops.

The costs and returns of various farm sizes in Suphan Buri and Nakhon Nayok were calculated and compared. It was found that, on average, farmers in both locations made a net profit of over 60 000 baht per crop. However, this aggregate picture was shown to be deceptive because the profits of large farms were a multiple of this amount whereas small- and medium-size farms incurred considerable losses. Experience was also found to determine farm success.

An estimation of the production technology of fish culture indicated that the main factors influencing yield were: seed, feed, (especially trash fish and broken rice), and fuel as a proxy for water changes. However, the use of these inputs was found to be at inefficient levels. Increasing the use of broken rice and fuel and decreasing the quantity of trash fish and the stocking rate would improve farm profitability.

With regard to government policy toward catfish farmers, the government should assist farmers, especially those with small farms and little experience to overcome the problems of high operating capital, insufficient knowledge, and high risk arising from the spread of catfish diseases. Appropriate short-term credit schemes and practical research and effective extension on

Table 6. Marginal physical product, input price, and price efficiency of 40 catfish farms in Suphan Buri, Thailand, 1979.[a]

	Fingerlings (x_1)	Trash fish (x_2)	Broken rice (x_3)	Fuel (x_5)
Regression R1				
MPP_i	0.022	0.090	–	2.52
VMP_i	0.423	1.755	–	44.63
P_i	0.936	2.350	–	4.75
VMP_i/P_i	0.452	0.747	–	9.40
Input use	Decrease	Decrease	–	Increase
Regression R2				
MPP_i	0.020	0.089	–	4.09
VMP_i	0.385	1.730	–	49.70
P_i	0.936	2.350	–	4.75
VMP_i/P_i	0.411	0.736	–	16.78
Input use	Decrease	Decrease	–	Increase
Regression R4				
MPP_i	0.017	0.051	0.982	2.95
VMP_i	0.341	0.996	19.120	57.54
P_i	0.936	2.350	3.000	4.75
VMP_i/P_i	0.364	0.424	6.373	12.11
Input use	Decrease	Decrease	Increase	Increase

[a] MPP_i = marginal physical product of input i; VMP_i = value of marginal product of input i ($MPP_i \times$ price of output); and P_i = price of input i.

the problems of disease, feed mix, and water management are necessary if catfish farming is to recover and realize its full potential in Thailand. It is encouraging that the National Inland Fisheries Institute of the Department of Fisheries is presently conducting research on catfish diseases, feed improvement, and water quality. It is hoped that successful results obtained in laboratories and experimental farms will become operational and be passed on to the farmers.

This study is based on a research project on the Economics of Catfish Farming in Thailand conducted at the Department of Agricultural Economics administered by the Kasetsart University Research and Development Institute (KURDI) and supported by the International Center for Living Aquatic Resources Management (ICLARM). The detailed results of this project are reported in Panayotou, T., Wattanutchariya, S., Isvilanonda, S., and Tokrisna, R., The Economics of Catfish Farming in Thailand, Department of Agricultural Economics, Kasetsart University, Bangkok, February 1981. The financial support of ICLARM and the collaboration of S. Isvilanonda and R. Tokrisna are gratefully acknowledged.

Discussion

Why was a dummy variable used to represent farm size when a quantitative measure, the size of farm in square metres, was available? Input and outputs had already been standardized and the purpose of inclusion of farm size as an explanatory variable was only to capture possible "scale economies." A quantitative measure of farm size was used, but it turned out to be statistically insignificant.

Is it socially desirable to feed trash fish to catfish for high-income groups (however profitable) when there are serious protein deficiencies among the poor in developing countries? The trash fish presently landed in Thailand are unsuitable for human consumption but recently efforts have been made to improve the handling and utilization of trash fish so that a part of the catch can be used for human consumption.

Should the degree of access to inputs such as credit be tested as a possible determinant of profitability? Farm size could be considered as a proxy for the degree of access to inputs but the possibility of using other, perhaps better, indicators cannot be ruled out.

Fish culture is site-specific; therefore, is it valid to compare productivity between different locations without explicit consideration of soil and climatic characteristics? Location was tested as an explanatory variable of yield but it was found to be statistically insignificant; however, there is also a need to examine the role of site selection within each location.

The interaction of economic and biological factors of production must be accounted for in production analyses. This was recommended as an important area for future collaborative research between economists and biologists. Additional areas for biological research were also identified: experimentation with alternative feed formulas and investigation of the relationship between water quality and disease.

Differences in approach between biologists and economists were noted: for instance, while economists focus on economics of production of a biomass of fish in the pond, biologists focus on individual biological relationships and the production of biomass. Hence, there is scope for involvement of economists at the experimental stage; experimental farm data can be used by economists to estimate yield curves considering separately individual growth and mortality rather than total biomass.

The last point raised concerned the role of externalities and, particularly, the effect on profitability of differential water quality among farms arising from upstream-downstream pollution. The need for a quantitative measure of the effect of water quality on productivity and profitability was identified.

Input-Output Relationships of Philippine Milkfish Aquaculture

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The existing gap between experimental yield and potential yield under field conditions and actual yield is highlighted. The determinants of actual yield are investigated by estimating a Cobb-Douglas production function relating yield to 11 explanatory variables. The inputs found to have a significant impact on output were stocking of fry and fingerlings, age of pond, farm size, fertilizers, and miscellaneous operating costs. Estimates of the marginal physical productivity of the inputs are used to study the optimization of input allocation, e.g., the optimum stocking rate at the given input prices. It is concluded that, at current prices, a profit-maximizing milkfish farmer in the Philippines should raise the stocking rate in deeper ponds and increase the use of supplementary inputs.

In a country where fish is one of the main sources of protein and aquaculture has a long tradition, fish culture can be expected to play an important role in supplying the fish needs of the country, especially in view of steadily rising fish prices. Moreover, the catch from capture fisheries is leveling off or even declining as limits to stock exploitation are reached. In the Philippines, however, aquaculture, which is predominantly milkfish culture (*Chanos chanos*), provides less than 10% of the total fish supply.

There are at present about 176 000 ha of brackish water ponds devoted to milkfish culture in the Philippines. The 1973–77 average milkfish production per year was about 110 000 t: an average yield of about 600 kg/ha/year. This low national average yield has been a perennial problem and a major concern for the Philippine government.

Past and present research on improved techniques of milkfish production have shown that the yields of Philippine milkfish ponds can be increased by at least threefold. In fact, such threefold increases in yields have been reported for a limited number of farms. Annual per hectare yields in excess of 2000 kg are attainable with the use of more inputs. As with all intensive production employing more inputs, its adoption is a question of economics.

Information on the technology and costs and returns of milkfish culture is already available. In fact, milkfish production has been the subject of numerous surveys to gather data on production practices in terms of input use. Their conclusions point to the importance of greater intensification of operations and management to increase milkfish production in the Philippines (Rabanal 1961; Tang 1967; Shang 1976; Librero et al. 1977; Chong 1980). Shang (1976) observed that rapid increases in the cost of fry and fertilizers are likely to discourage producers in the Philippines from adopting intensive farming techniques. However, the use of expensive inputs can be profitable if properly carried out as Shang demonstrated for Taiwan.

Why then has milkfish culture not played a bigger role in the Philippines? Why have milkfish yields been perennially low in spite of the availability of improved technology? This study attempts to answer these questions by assessing the responses of milkfish production to supplementary inputs and by quantifying a few input-output relationships of milkfish production in the Philippines.

Although supplemental inputs have to be used to improve the productivity of milkfish ponds (intensification of operations), the uncertainty of output response due to inputs affects a producer's decision on the use and rates of use of such inputs. As a result, the producer is naturally interested in knowing the costs and benefits (and

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risks) involved in increasing inputs. The present study addresses this concern and shows the responses of milkfish production to various inputs.

Inputs are not applied uniformly throughout the country. There is, therefore considerable geographical variation in output. Some of this could, however, be due to differences in environmental conditions such as soil type, climate, or pH. This study concentrates on output variability related to inputs.

Soil type, climate, and pH, although important factors in determining output initially, cannot explain all the yield differences observed in the country. Like all production activities under human control and management, the limitations on production in milkfish culture are related to the use of inputs.

Objectives

(1) To estimate the input-output relationships (production function) for milkfish production in each of seven selected provinces in the Philippines, and for the whole country.

(2) To determine the marginal productivities and returns of inputs used in different quantities and proportions.

(3) To derive the optimum rates of application of the various inputs used in producing milkfish by using the estimated functions and 1978 prices.

(4) To show which inputs are the most important determinants of total output.

(5) To analyze variations in Philippine milkfish production by province.

(6) To use the estimated production function (or model) to predict production levels from given levels of input application.

Methods

Data Collection

A working knowledge is necessary of the production operations for which functional input-output relationships are to be empirically estimated to correctly specify the production function and collect the appropriate data. Data were obtained through a cross-section survey of producers in seven provinces of the Philippines covering the production period January–December 1978.

The most common and widely practiced method of production is the use of a farm layout comprising nursery, transition, and rearing (grow-out) ponds. The sample for this study consists of milkfish producers whose farms are of this design. The average size of such a farm is about 16 ha. The provinces covered in the survey are, from north to south, Cagayan, Pangasinan, Bulacan, Masbate, Iloilo, Bohol, and Zamboanga del Sur. A minimum of 30 respondents per province was taken as a sample. The largest number of respondents, 81, was from Pangasinan. Purposive sampling was used to obtain as homogeneous a group of milkfish operators as possible to eliminate differences in production techniques and to obtain data from a range of farm sizes and rates of input use. Only milkfish operators who use supplementary inputs are included in the sample.

It was not possible, however, to restrict the sample to farms that monoculture milkfish. Some farms that culture milkfish and penaeid shrimp were also retained in the sample, but the output and the corresponding value of penaeid shrimp were not considered in the analysis.

Because 1978 was used as the reference period for the information collected, the 1978 price structure of inputs and output was adhered to. Also, information collected is based on quantities of inputs actually used and not those available for use.

The data were collected by a core group of 8–10 closely supervised enumerators, assisted by two additional enumerators in each province. The same group was also involved in preparing the data for processing to avoid errors in interpretation, coding, computation, and analysis.

It is not always easy to obtain the data required for production function estimation. Two types of data are frequently used: field survey and experimental data. One thing common to both types of data is that there are variables that may be difficult to measure. While it is true that data from controlled experiments are relatively homogeneous, that is, there are no differences in the quality of inputs, results from analysis using experimental data have limited applications. This is because experiments are of necessity conducted on a small scale and they seldom capture and replicate actual variations in field conditions. Consequently, their usefulness in national policy formulation is correspondingly limited. On the other hand, because a survey can be conducted over a wide geographical area, the results of survey data have broader applications. Our survey, which has this wide coverage, thus reflects a variety of actual farm conditions.

Milkfish Production Function Model

Three algebraic forms of the production function model were initially estimated to determine their appropriateness and explanatory/predictive power. These were the linear, quadratic, and Cobb-Douglas forms although a wider range could be considered. The functional form of the milkfish production model chosen based on its explanatory power is that of an unconstrained Cobb-Douglas production function model. The specified function is an acceptable representation of the underlying mechanics of the production process.

Milkfish production results from combining various fixed and variable inputs in a body of water. Eleven inputs or explanatory variables were hypothesized to explain milkfish production. To evaluate the relative influence of each of the 11 inputs or explanatory variables on the output of milkfish, the model is estimated by using multiple regression techniques.

The basic Cobb-Douglas model specified is:

$$Y = \alpha_o X_1^{\beta_1} X_2^{\beta_2} X_3^{\beta_3} X_4^{\beta_4} X_5^{\beta_5} X_6^{\beta_6} X_7^{\beta_7} X_8^{\beta_8} X_9^{\beta_9} X_{10}^{\beta_{10}} X_{11}^{\beta_{11}} \epsilon$$

$$\log Y = \log \alpha_o + \beta_1 \log X_1 + \beta_2 \log X_2 + \beta_3 \log X_3 + \beta_4 \log X_4 + \beta_5 \log X_5 + \beta_6 \log X_6 + \beta_7 \log X_7 + \beta_8 \log X_8 + \beta_9 \log X_9 + \beta_{10} \log X_{10} + \beta_{11} \log X_{11} + \epsilon$$

where Y = output of milkfish (kg); X_1 = age of pond (years); X_2 = milkfish fry (pieces); X_3 = milkfish fingerling (pieces); X_4 = acclimatization (hours); X_5 = hired labour (man-hours excluding caretaker's time); X_6 = miscellaneous operating costs (peso); X_7 = milkfish culture experience (years); X_8 = pesticides (peso); X_9 = organic fertilizers (kg); X_{10} = inorganic fertilizers (kg); X_{11} = land (ha); α_o, β_i = regression coefficients (parameters) to be estimated; and ϵ = random error or disturbance term.

The explanatory variables (X_i) or inputs are sometimes known as target variables because they are subject to influence by the decision-maker (producer or policymaker). Of the 11 explanatory variables specified in the model, all but age of pond are within the control of producers. The production coefficients (β_i) or exponents in the Cobb-Douglas form are the elasticities of production. The β_i terms are actually transformation ratios of the various inputs used in milkfish production at different quantities. Depending on the need of the study, the basic model can be modified, as reported in the section on results.

So far no mention of the expected signs of the parameters has been made. The Cobb-Douglas form does not allow signs to be attached, unlike the quadratic form where a parameter can be expressed as $-\beta_i X_i^2$, for example. However, the marginal products as distinct from the parameters are expected to have either positive or negative signs.

Two basic functions were estimated: one on a per farm basis and one on a per hectare basis. Estimating a production function calls for accurately measured data on output and inputs. Faulty data have often been the source of poor fit and insignificant estimates. Recognizing the importance of accurate data, brief discussions of the variables used in estimating the production function and the problems of measurement are provided.

This is of necessity only an approximate modeling of the true production process because there exist several variables such as pond depth and water salinity that may be important in explaining variation in milkfish production but that have not been included.

Total Output

Total output refers to the quantity of milkfish harvested (in kilograms) during the 1978 production year. Other species such as shrimp, tilapia, and mullet have been excluded from the total. This figure includes the milkfish that are consumed at home, given away as gifts, and the harvester's and caretaker's shares. The total output, therefore, reflects all milkfish harvested from the pond — marketed as well as non-marketed. Whenever possible, losses due to typhoon and floods were estimated and included in total output. Milkfish harvested before final harvest are also reflected in total output, because one characteristic of Philippine milkfish production is that some fish are harvested well before the final harvest; to entertain guests who drop in at the farm, for subsistence, and for festivals. It was not possible to determine the extent of such practices and the magnitude of output that went unrecorded. This and other data collection problems such as accuracy in counting stocking material (fry) are dealt with below.

Types of Inputs

Following De Wit (1979), inputs can be classified as material inputs, management inputs, and input of field work (labour). Material inputs can be further categorized as either yield-increasing inputs such as fertilizers, or yield-protecting inputs such as pesticides.

Besides these material inputs, management inputs and input of field work, other inherent characteristics of the pond environment, and/or factors affecting its environment such as age of the pond and weather can be employed to explain milkfish output. Again, a working knowledge of these other factors can be invaluable to the milkfish producer.

Results and Discussion

The Estimated Production Function

The main results of the estimation of the milkfish production function for the whole country are summarized in Tables 1 and 2. The estimates of the production coefficients, their standard error, and the coefficient of determination are also reported. The usefulness of the estimates of the various production coefficients of milkfish culture is discussed to provide the reader with a more thorough understanding of the underlying input-output relationships. In general, the levels of statistical significance of the estimated production coefficients are encouraging.

One can interpret the positive production coefficients and marginal physical products of the respective inputs as implying that an increase in output of milkfish can be accomplished by

Table 1. Estimated production function (Cobb-Douglas), sample means, and estimated output for Philippines on a per-farm basis (Equation 1).

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}
Intercept = 10.91											
Production coefficients	0.28	0.14	0.10	0.04	–0.01	0.16	0.04	0.03	0.03	0.09	0.57
T-value	4.70	5.37	4.25	1.00	–0.29	3.21	0.65	1.09	1.96	3.42	9.26
Standard error	0.05	0.02	0.02	0.04	0.02	0.05	0.06	0.02	0.01	0.02	0.06
Significance level	0.0001	0.0001	0.0001	0.32	0.77	0.001	0.51	0.27	0.05	0.0007	0.0001
R^2	77										
Input mean ($\overline{X}$)											
GM	12.84	3543	2346	3.74	123.26	639.56	10.28	27.79	630.44	74.77	6.16
AM	21.57	5940	5892	14.09	228.71	1033.06	15.72	62.46	2178.83	172.33	16.20
Estimated output at $\overline{X}$ = 2577											
Marginal product	57.25	0.11	0.11	28.10	–0.22	0.60	10.24	2.85	0.13	3.21	243.40
Average price of input	—	0.09	0.18	—	—	—	—	—	0.29	1.66	—

Note: GM is the geometric mean, AM is the arithmetic mean, and the F-value = 95.3.

Table 2. Estimated production function (Cobb-Douglas), sample means, and estimated output for Philippines on a per-hectare basis (Equation 2).

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}
Intercept = 7.01											
Production coefficients	0.27	0.18	0.14	0.05	–0.01	0.17	0.04	0.02	0.04	0.12	–0.02
T-value	4.56	6.22	4.88	1.22	–0.35	3.36	0.55	0.46	2.24	3.43	–0.57
Standard error	0.05	0.02	0.02	0.04	0.02	0.05	0.06	0.03	0.01	0.03	0.04
Significance level	0.0001	0.0001	0.0001	0.22	0.72	0.0009	0.58	0.64	0.02	0.0007	0.57
R^2	39										
Input mean ($\overline{X}$)											
GM	12.84	3543	2346	3.74	123.26	639.56	10.28	27.79	630.44	74.77	6.16
AM	21.57	5940	5892	14.09	228.71	1033.1	15.72	62.46	2178.8	172.3	16.20
Estimated output at $\overline{X}$ = 1351.44											
Marginal product	28.40	0.06	0.06	18.12	–0.11	0.38	5.26	0.96	0.08	2.13	–4.40
Average price of input	—	0.09	0.18	—	—	—	—	—	0.29	1.66	—

Note: GM is the geometric mean, AM is the arithmetic mean, and the F-value = 18.3.

increasing the intensity of input use. On the other hand, negative coefficients and marginal products suggest that use of that particular input should be reduced.

Selected production functions were used to derive some technical and economic relationships. In addition, values of the respective inputs at their geometric means were substituted into the selected production functions to obtain the predicted average milkfish yield. Economic optima were calculated to show whether, on average, input combinations are efficient. From this, it can be shown whether input use can be increased or decreased to maximize profits.

Fit of the Model

In general, the Cobb-Douglas equation fitted the data well as indicated by the F-values and R^2. With the exception of Cagayan, the F-values were highly significant in all cases. All the R^2 values are also statistically significant, ranging from 0.39 to 0.89. Their occasional modest values are not unusual in multiple regression analysis using cross-sectional data. Lastly, there appear to be no problems with dominant variables or multicollinearity.

Nature of Input-Output Responses

A revealing result of this study is that for the most part, inputs applied at the reported levels do influence milkfish output. The 11 variables hypothesized to explain milkfish yield explain 39 to 89% of the variation in milkfish output.

Because a large interest of this study was to examine the nature of the input-output relationship and to test the significance of each of the estimates of the production coefficients, all the coefficients will be reported even though some of them are not significant as shown by their low t-values. In all cases there are sufficient degrees of freedom for statistical tests. More than 50% of the regression or production coefficients are significant at small probability levels. Errors due to memory recall may have contributed to the presence of some insignificant coefficients.

In general, an examination of the magnitudes of the coefficients estimated for the per farm and per hectare production functions by province, showed slight variations between the two coefficients estimated for the same explanatory variable. Signs of the estimated coefficients were found to be consistent with theory and technical knowledge of the production process. Selected production functions were used to derive broad economic and technical conclusions. Wherever appropriate, attempts were made to relate the results of the study to the current problems of the industry.

Economic Optima Defined

To realize maximum net returns, producers must find out the rates at which to apply the inputs. To do this, they will need to have information on the productivities of the inputs they use. Given the prices of inputs and the output prevailing in the factor and product markets, and with the help of the estimated production functions, optimum input combinations can be calculated. At the point of optimum input combination, the ratio of input-output prices should equal the marginal product for each of the inputs used. In other words, the value of the marginal product must be equated to the input price. If the marginal product is greater than the input-output price ratio, $MP_i > P_i/P_o$, then the use of that input should be increased. If the marginal product is less than the price ratio, the use of that input should be decreased. Similarly, if the marginal product and price ratio are equal, it means that producers are economically efficient.

From the Cobb-Douglas production function, marginal products of input application can be computed from the production coefficients and average products, or by differentiating the production function. In this study, marginal products were derived by differentiating the production function with respect to the particular input of interest, with other variable inputs calculated at their geometric means (as opposed to arithmetic mean). Using arithmetic means gives biased marginal products. An actual example will be provided to show how the economic optima were calculated for a few selected inputs for which price data were available.

Philippine Milkfish Production Functions

In this section, two production functions are discussed in detail to provide an appreciation of how production function analysis can be a useful tool to aid decision-making on the farm. The first production function represents a whole farm production relationship; the second uses data standardized on a per hectare basis. The first of these two estimated input-output relationships will be used in the following discussion to show how powerful production function analysis can be.

Farm Basis: (Equation 1)

$$Y_F = 10.9 X_1^{0.28} X_2^{0.14} X_3^{0.10} X_4^{0.04} X_5^{-0.01} X_6^{0.16} X_7^{0.04} X_8^{0.03} X_9^{0.03} X_{10}^{0.09} X_{11}^{0.57}$$

Hectare Basis: (Equation 2)

$$Y_H = 7.0 X_1^{0.27} X_2^{0.18} X_3^{0.14} X_4^{0.05} X_5^{-0.01} X_6^{0.17} X_7^{0.04} X_8^{0.02} X_9^{0.04} X_{10}^{0.12} X_{11}^{-0.02}$$

Of the 11 explanatory variables in the model, 6 variables in the case of Equation 2 and 7 variables of Equation 1 are significant (see Tables 1 and 2). These variables are: age of pond (X_1); milkfish fry (X_2); milkfish fingerling (X_3); miscellaneous operating costs (X_6); organic fertilizers (X_9); inorganic fertilizers (X_{10}); and farm size (X_{11}). The other variables are not significant in explaining milkfish output.

The summation of all the production coefficients ($\Sigma\beta_i$) for Equation 1 is equal to 1.47. This means that the production function exhibits increasing returns to scale; that is, if all the inputs specified in the function are increased by a certain percentage, milkfish output will increase by a larger proportion. In the example above, if all inputs are increased by 1.0% output will increase by 1.5%.

Further, an examination of Equation 1 shows that a 1% increase or change in the number of pieces of milkfish fry, X_2, will result in a 0.14% increase or change in milkfish output, other inputs held constant.

Miscellaneous operating costs (X_6), which include depreciation, repair and maintenance, taxes and other fees, interest expenses, food for labourers, etc., account for about one-sixth of the final output. Similarly, yield-increasing inputs (organic and inorganic fertilizers) contribute about one-thirtieth and one-eleventh of milkfish output. The minimal response of output to these inputs can be attributed to the current rates of application of these three inputs in shallow ponds. If farm size (X_{11}) is increased by 1%, output will increase by almost 0.6% as indicated by the coefficient of farm size, X_{11} of 0.57. The signs of the production coefficients are consistent with theory and the logic of the production process. Further, the R^2 or coefficient of determination is about 77% and the F-test of the overall regression is significant at the 0.0001% level (F-value, 95.3). Tables 1 and 2 spell out the other details regarding the farm and hectare basis production functions. Just like the farm basis production function, the hectare basis function can be interpreted in a similar fashion.

Theoretically, no output is forthcoming if no inputs are used. Equation 1 also shows an intercept or constant value of 10.9 (antilog of the intercept). This result arises from the nature of the mathematical form of the equation: the intercept term enters the equation multiplicatively. Although the value of the intercept is low, it is important from the technical point of view. It indicates the level of efficiency of the milkfish production process in transforming inputs into milkfish output. A value of 10.9 implies that milkfish production in the Philippines as a whole is inefficient, because the intercept values for the more productive provinces of Iloilo and Bulacan were respectively, 82.0 and 290.0.

Value of Marginal Product

As discussed previously, at the point of optimum input combination, the ratio of the input-output prices to marginal product must be the same for each of the inputs used. This is written algebraically as follows: $MP_i = P_i/P_o$; or $MP_i \times P_o = P_i$; or $VMP_i = P_i$; where MP_i = marginal product of input i; P_i = price of input i; P_o = price of output or milkfish; and VMP_i = value of marginal product.

Optimum Stocking Rate

The optimum stocking rate of milkfish fry (X_2) is calculated using the production function (Equation 1) estimated for the Philippines, the geometric means of all other inputs, the price of milkfish fry in 1978, and the farmgate price of market size milkfish in 1978.

$$Y = 10.9 X_1^{0.28} X_2^{0.14} X_3^{0.10} X_4^{0.04} X_5^{-0.01} X_6^{0.16} X_7^{0.04} X_8^{0.03} X_9^{0.03} X_{10}^{0.09} X_{11}^{0.57}$$

Taking the partial derivatives of Y with respect to X_2 gives the marginal product of X_2:

$$\frac{\partial Y}{\partial X_2} = 1.5 X_1^{0.28} X_2^{-0.86} X_3^{0.10} X_4^{0.04} X_5^{-0.01} X_6^{0.16} X_7^{0.04} X_8^{0.03} X_9^{0.03} X_{10}^{0.09} X_{11}^{0.57}$$

Having obtained $\partial Y/\partial X_2$ or the MP of the milkfish fry stocked, the price ratio of input to output is then determined.[3] $P_{X_2}/P_Y = 0.36/6.29 = 0.057$. That is,

$$1.5 X_1^{0.28} X_2^{-0.86} X_3^{0.10} X_4^{0.04} X_5^{-0.01} X_6^{0.16} X_7^{0.04} X_8^{0.03} X_9^{0.03} X_{10}^{0.09} X_{11}^{0.57} = 0.057$$

[3]Based on four pieces to 1 kg of market size milkfish. Each milkfish fry costs P0.09, thus, four pieces of fry equal P0.36. The average farmgate price of milkfish is estimated at P6.29/kg in 1978 (as of 1982, P8.29 = U.S.$1.00).

And solving for X_2:

$$X_2^{-0.86}(1.5)(2.04)(2.17)(1.05)(0.95)(2.81)(1.10)(1.10)(1.21)(1.47)(2.82) = 0.057$$

$$113\ X_2^{-0.86} = 0.057$$
$$X_2^{-0.86} = 0.057/113 = 0.0005$$
$$X_2 = 6790 \text{ pieces of milkfish fry per hectare.}$$

Therefore, the optimum stocking rate for the country as a whole is 6790 pieces of milkfish fry per hectare per year. The implicit assumption for this economically determined stocking rate is that the milkfish survival rate has already been taken into account in the input-output relationship through the raw data.

If this optimum stocking rate is now compared to the arithmetic and geometric means of Philippine milkfish fry stocking rate of 5940 and 3540, respectively, it is apparent that the average Philippine milkfish farmer can profitably increase present stocking rates. However, producers with shallow ponds probably will not benefit from increased stocking rates unless they deepen their ponds.

At this point, a word to elaborate on the conclusion will help clarify the implications of the study result. Although it is true that each milkfish farm has its own individual production function, the production function estimated and presented above is the industry function in so much as it portrays an average input-output relationship for all the farms in the industry. Therefore, the production function for any one particular farm may conceptually be obtained from this industry function in terms of the farm's ability to implement optimal values of the parameters in the industry (Aigner and Chu 1968). The two authors point out that possibly all farms do not operate anywhere near the industry (or frontier) production function; their output lying below this frontier.

Based on the same production function, the optimum stocking rate for milkfish fingerling is calculated to be 2154 pieces of fingerlings per hectare per year. This economically determined stocking rate is about 60% lower than the national average stocking rate of 5892 pieces (arithmetic mean) or about 10% lower than the geometric mean (2346) of the national milkfish fingerling stocking rate. Therefore, the stocking rate of milkfish fingerlings can be cut back at current levels of input application if maximum financial returns are the objective of production. The most important thing to bear in mind is that current levels of input application in shallow ponds cannot help to support higher fingerling stocking rate. As such, fingerling stocking rate can be reduced to save unnecessary expenditures.

The difference between the price of fry and fingerling partly explains the optimal values obtained for fry (to increase) and fingerlings (to decrease). Based on 1978 price data, milkfish fingerlings are twice as expensive as milkfish fry. The implication is that milkfish fry is a more economic stocking material. In fact, only 13% of the sampled milkfish farmers use fingerling as stocking materials.

Another way to demonstrate the economic gains from increased fry stocking rates is to show the inequality of the two sides of the relation between the value of marginal product and input price. This is: $MP_i \times P_0 = P_i$; $0.11 \times 6.29 = 0.09 \times 4$ pieces; $0.69 > 0.36$

Obviously, the left-hand side of the identity is greater than the right-hand side. Because the input-output price ratio is given or exogeneously determined,[4] nothing can be done to influence it. Only the left-hand side of the identity can be changed to affect its magnitude. This can be effected by increasing the stocking rate until the marginal product (and VMP) declines further due to diminishing returns. The milkfish fry stocking rate is deemed optimum when the equality is again restored (see section on optimum stocking rate).

For milkfish fingerlings, it can be shown that the left-hand side of the identity is smaller than the right-hand side. By reducing the fingerling stocking rate, the MP of fingerlings will become larger, until the equality is restored again.

The optimum stocking rate is calculated based on four pieces of fish to a kilogram. An additional market dimension that complicates this straightforward relationship is the market price in relation to size of fish. In some markets, the bigger the fish the higher the price per kilogram, whereas in other markets, the relationship is inverse, that is, the bigger the fish the lower the price per kilogram. Thus, it is clear that once the input-output relationship has been estimated, the rates at which inputs are applied are dictated by the average per kilogram of output as well as the prices of inputs.

Optimum Application Rates of Fertilizers

Organic fertilizers: If the milkfish farmer took into account the price of organic fertilizers and the price of milkfish he would apply only 1750 kg/ha/year. Thus, according to the production function (Equation 1), milkfish producers

[4]In perfectly competitive markets, prices are taken as given.

can increase their organic fertilizer application and increase their output and returns. The optimum organic fertilizer application rate is about 175% higher than the geometric mean (630) of organic fertilizer applications in the country. This finding to increase fertilizer application is consistent with the conclusion suggesting an increase in the stocking rate of milkfish fry.

Inorganic fertilizers: Inorganic fertilizers should be applied at a rate of 1124 kg/ha/year if the price of milkfish is P6.29 and the price of inorganic fertilizers is P1.66/kg. The price of inorganic fertilizers in terms of a kilogram of the fertilizer including its fillers must be distinguished from the price of a kilogram of its nutrients (NPK). The type of inorganic fertilizers is crucial if these fertilizers are used in ponds suffering from acid sulfate soils. For example, 16-20-0, which is ammonium sulfate phosphate, is very acidic and using this type of fertilizer would further compound the problem of acid sulfate soils of existing ponds. The use of such "acidic" fertilizers would, therefore, necessitate periodic liming to correct/restore pond pH. This implies that additional production costs can be avoided if the proper fertilizers (less acid forming) are used.

The point to be stressed from this brief discussion is that input use recommendations in the absence of explicit price considerations (and relating these to the marginal products of the respective inputs) is not useful from the management point of view. This is the basic difference between profit maximization and output (biomass) maximization.

Explicit input subsidies or price support for milkfish is unheard of in the Philippines. There is, however, fertilizer subsidy for Priority I and II crops, and milkfish are a Priority II crop. Input subsidization or price support can make the added use of inputs profitable where before it was uneconomic. Research to determine optimum input combinations and optimum output level must, therefore, recognize the presence or absence of such government support.

Estimated Output

Equation 1 can also be used to predict or estimate the output of milkfish. The estimated output can be calculated at one of three points: at the point of maximum biomass production (physical measure) or total product; at the point of maximum profits (value measure); or at the input means (in this case, the geometric means) of application. For this study, only the third method of calculation is used.

A total of about 2500 kg/ha/year of milkfish output is predicted from the industry production function as represented by Equation 1 if the milkfish producer applies inputs at the means in ponds that are deeper and not in existing shallow ones. This 2500 kg/ha/year estimated output has been obtained using the industry function and is not based on individual farm production functions (Aigner and Chu 1968). However, because a large majority of milkfish producers do not apply as much inputs and their ponds are shallow, actual output of milkfish is thus correspondingly much lower.

Summary and Conclusions

In this study, the concept of the production function, describing a relation between 11 inputs or explanatory variables and milkfish output, has been employed. The optimal application of the different inputs in response to prevailing 1978 prices of inputs and output was calculated for a small number of inputs whose prices were readily available.

This study was undertaken in response to a need for information on the productivity of inputs used in Philippine milkfish production. Based on the empirical results of the study, Philippine milkfish ponds have available potential that is not yet realized. Higher output can be obtained through the use of more inputs in deeper ponds that is, intensifying production methods. The analyses of the input-output relationships of Philippine milkfish production have shown the economic benefits that are foregone from using too many inputs in existing shallow ponds and, second, from not using more inputs in deeper ponds.

The survey data have shown that the average milkfish production per hectare from existing ponds is 761 kg/year. To be sure, this estimated yield is higher than the reported national average of 600 kg/ha/year. This is because the survey data consist of production data from farms using inputs; milkfish farms that did not use any inputs were excluded from the survey. With proper husbandry, management, and deeper ponds, milkfish yield can be increased to at least 2 t, or about three times higher. If the increase in output comes from hectarage expansion with existing practices it will require at least 3 ha of land to produce 2 t of milkfish; it can be produced in 1 ha with proper management in deeper ponds. However, these two alternatives have to be evaluated for their costs and benefits to determine which of the two should be recommended.

Next, only interfarm (cross-section) production functions have been estimated. This is because lack of data precluded the estimation of intrafarm (time-series) production functions. As such, these interfarm functions should be regarded as representing the average farm in the industry.

Although it is true that each milkfish farm has its own individual production function, the production functions estimated using the cross-section data are judged to be realistic approximations of the "real" industry function. The estimated overall production functions will nevertheless have applications to existing farms in the country. In fact, Aigner and Chu (1968) state that the production function for any particular farm may conceptually be obtained from the industry function in terms of the farm's ability to implement optimal values of the parameters in the industry. We would also argue that most farms do not operate near the industry production function; their output lies below the industry production function.

Several algebraic forms of production functions were fitted to the data. However, the algebraic form selected for interpretation and application in this study is the Cobb-Douglas production function. The Cobb-Douglas form was used to estimate input-output relationships by province. In general, the Cobb-Douglas form fits the data well as revealed by the highly significant F-values and relatively high R^2.

The low absolute values of the estimated production coefficients reflect the inadequacy of existing shallow ponds to make full use of present rates of input application. Milkfish yield is responding poorly to the present quantities of inputs applied in these shallow ponds. This implies that if the milkfish producers in the country switch to the use of deeper ponds with larger quantities of inputs, output will increase. Experiments with higher levels of input applications in deeper ponds have shown that milkfish yields can be increased significantly. In this case, there is thus a strong response to larger quantities of inputs in deep ponds as compared with the poor response of milkfish to present levels of input used in shallow ponds.

The authors believe that the reluctance of producers to use more inputs and also to pay more attention to management of their milkfish farms may be attributed to the prices of both inputs and output. Perhaps, if there is a government subsidy for inputs and price support for milkfish, producers may be encouraged to intensify their production.

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The 324 milkfish producers in the country who willingly cooperated in the project deserve special mention, without whose cooperation this project would not have materialized. For the privilege of working with them, we are thankful. The authors also wish to thank Ian R. Smith and Roger S.V. Pullin for their helpful comments on an earlier draft of this manuscript.

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Discussion

Why were the coefficients for fry and fingerling different? Is it due to different mortalities of fry and fingerlings? The different mortalities have already been taken into account through the raw data. The difference, therefore, may be due to the fact that while fry are acclimatized in the same pond before being released, the fingerlings purchased from other pond operators enter the pond as a new environment. To capture such differences one suggestion was to use a dummy variable for the fry–fingerling classification.

It was observed that, besides the biological and economic dimensions, one should also bring in the social dimension to explain yield. Factors like ownership pattern, indebtedness of the farmers, and marketing arrangements can influence output significantly. The authors reported that they had estimated the production function separately for government-leased and privately owned ponds and that the latter are more efficient.

The inclusion of miscellaneous operating costs as an explanatory variable in the production function was questioned. This is a value aggregate of seven variables. Doubts were also expressed concerning measurement of scale economies in terms of the sum of the input elasticities when some of the latter parameters were not statistically significant. It was suggested that this problem could be handled by testing whether the sum of the input elasticities differed from unity.

What is the role of depth of ponds? Farms with shallow ponds would not benefit by raising the stocking rate. The estimated production function is only an average one involving both deep and shallow ponds.

Why was experience not a significant variable? Maybe the question asked in the survey: "How many years of milkfish culture experience do you have?" fails to distinguish between experience with the old method and experience with the improved method of production. It is the latter that counts.

How can one make the biological optimum and the economic optimum compatible? Can one suggest precise numerical changes in the amounts of inputs based on the economic optima? It was observed that the biological and economic optima were the outcome, respectively, of an output maximization and a profit maximization objective. It was also noted that only small numerical changes in the neighbourhood of the estimated production function could be suggested.

Economics of Taiwan Milkfish System[1]

Chaur Shyan Lee[2]

This paper examines the entire milkfish system in Taiwan, including fry gathering and marketing, baitfish production, market-size rearing, and marketing. A constant elasticity of substitution (CES) production function is used to estimate input-output relationships for baitfish and market-size production systems, with all inputs classified into labour and capital. An important finding is that the elasticity of substitution between labour and capital exceeds unity indicating rather easy substitutability between the two inputs. Rates of return to marketing intermediaries were found to be high for both fry and market-size milkfish.

The fisheries sector, including aquaculture, has played a significant role in the agricultural development of Taiwan. The relative importance of this sector can be seen in the fact that its share of total agricultural production increased from 11% in 1950 to 21% in 1979, while the share of crop production declined from 64% to 48%.

Intensive land use is a tradition in Taiwan. Farmers have found it necessary to grow crops and raise animals year-round wherever possible and have changed from crops to fish culture to maximize the profit from their farmland and to sustain their levels of living. The area devoted to fish culture has increased from 38 148 ha in 1965 to 60 460 ha in 1979. Milkfish is the most important species cultured in Taiwan; in 1979, 15 346 ha, or about 26% of the total area was used for milkfish.

Basic biological research on milkfish in Taiwan has been intensive, but there have been few economic studies of production. Moreover, there has been no economic analysis of the fry input sector nor of the marketing of milkfish in Taiwan. The Taiwanese milkfish industry faces a chronic shortage of fry and must rely on imports from the Philippines and Indonesia for almost half its annual requirements. Demand for milkfish fingerlings has grown because the fish has been found to be a suitable baitfish for the tuna long-liners based in Kaohsiung and Tung-Kang, the southern parts of Taiwan. However, many milkfish producers are finding that the rearing of shrimp and other freshwater fish is more profitable than rearing market-size milkfish. Because of the importance of milkfish as a protein source, the government is anxious to maintain production. Thus, a systematic economic analysis of production and marketing of milkfish is needed to assist the government in its programs to sustain milkfish production and the incomes of producers and other support groups within the sector.

This research was undertaken to produce an economic analysis of the production and marketing of milkfish, and specifically to: (1) examine the gathering and marketing of milkfish fry; (2) measure the production efficiency of the baitfish industry; (3) analyze the input-output relationship of production of market-size milkfish; and (4) understand the marketing of market-size milkfish.

Methods

A number of indicators can be used for an economic analysis of production and marketing of milkfish and they will be discussed separately.

Production Aspects

Benefit-Cost Ratio

Benefit-cost analysis has become increasingly popular and useful because it can be used to compute the direct and indirect costs and benefits of a specific enterprise. The benefit-cost ratio of a

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specific enterprise is: K = FI/TC, where FI is farm income and is equal to the difference between farm receipts and production costs, and TC is total cost of production.

Rate of Farm Income

The rate of farm income is also an indicator of production efficiency and can be computed using the formula: R = FI/FR, where FI is farm income and FR is farm receipts. From the point of farm management, FR is equal to farm income and farm expenses. Based on this equation we can see that the larger the rate of farm income, the greater the production efficiency.

Factor Productivity

Factor productivity is a reciprocal concept of production efficiency and is measured as output per unit of input. Setting farm output as Q, input of farmland as D, labour as N, and capital as C, land, labour, and capital productivity can be explained by Q/D, Q/N, and Q/C, respectively. Factor productivity can be derived from the relationship between factor productivity and the factor–factor ratio. For example, land productivity can be explained by: (1) the relationship between land productivity and labour productivity and the labour–land ratio; or (2) the relationship between land productivity and capital productivity and the capital–land ratio. The factor productivity can be explained by the following formulas:

$$\text{Land productivity}: \frac{Q}{D} = \frac{Q}{N} \bullet \frac{N}{D};\ \frac{Q}{D} = \frac{Q}{C} \bullet \frac{C}{D}$$

$$\text{Labour productivity}: \frac{Q}{N} = \frac{Q}{D} \bullet \frac{D}{N};\ \frac{Q}{N} = \frac{Q}{C} \bullet \frac{C}{N}$$

$$\text{Capital productivity}: \frac{Q}{C} = \frac{Q}{D} \bullet \frac{D}{C};\ \frac{Q}{C} = \frac{Q}{N} \bullet \frac{N}{C}$$

From the first of these equations, land productivity from labour used, we can see that if the labour–land ratio is held constant, the increase of land productivity (Q/D) is entirely due to the increase in labour productivity. For land productivity from capital input, if the capital–land ratio (C/D) remains constant, the increase in land productivity (Q/D) is totally due to the increase in capital productivity.

Elasticity of Substitution

With two factors of production, labour (N) and capital (C), the elasticity of substitution is:

$$\sigma = \frac{(C/N)\ d\ (N/C)}{(f_n/f_c)\ d\ (f_c/f_n)}$$

where f_n and f_c are the marginal products of labour and capital, respectively. The elasticity of substitution is the proportional change in the relative factor inputs to a proportional change in the marginal rate of substitution between labour and capital (Brown 1968, p. 18). The elasticity of substitution is an important indicator of production efficiency.

A CES (constant elasticity of substitution) production function was used to measure elasticity of substitution in this study. The CES production function is:

$$Q = \gamma\ (k\ C^{-\rho} + (1 - k)\ N^{-\rho})^{-v/\rho}$$

where Q, C, and N represent output, capital, and labour inputs, respectively, and γ is a scale parameter denoting the efficiency of a production technology, k is the distribution parameter indicating the degree to which technology is capital intensive; v represents the degree of homogeneity of the function or the degree of return to scale; and ρ is the substitution parameter equal to $(1 - \sigma)/\sigma$, where σ is the elasticity of substitution. Then we can estimate σ, where $\sigma = 1/(1 + \rho)$.

Marketing Aspects

Marketing Channels

Marketing channels must be studied to understand the marketing system and the relation of markets and market agencies to one another. The channel represents the movement of products from producers to consumers and involves several market agencies. The farmers use different marketing channels depending on the quantity of product they have for sale. Small producers of milkfish may sell to dealers or wholesalers, whereas large producers may ship directly to one of the city markets.

Marketing Margins

In the agricultural sector, the marketing margin is the retail price less the farmgate price. Margins at different market agencies vary widely with the type of products handled. Generally, they are higher for perishable products.

Marketing Costs

Marketing costs are service charges on marketing. Generally speaking, marketing costs reflect the country's economy and are closely related to the degree of industrialization of the economy. These costs can be calculated from the price paid at the point of production, the wholesale and retail prices paid where the goods are consumed, and the marketing expenses, such as assembly, transportation, freezing, profit, and market management fees. We can then determine what share of the consumer's dollar goes to the producer and how much goes for marketing.

Price Variation

Price variation can be explained by an index of seasonal variation and by price instability measured by the Michaely index and Von-Neumann ratio (Michaely 1962; UNCTAD 1968). The data for this study were gathered in a field survey of approximately 220 fry gatherers and dealers, baitfish producers, milkfish producers, and marketing intermediaries in 1979. In addition, secondary data on production and prices were obtained from various publications of official institutions in Taiwan.

Gathering and Marketing of Milkfish Fry

Fry Gathering

Milkfish fry are procured from coastal waters. The main sources of fry are located on the southern and eastern coasts of the island. However, there are significant regional variations in procurement and during 1977–79 the eastern coast accounted for about 83% of the total fry catch. The total procurement of fry varies widely from year to year due to meteorological and oceanic changes that affect milkfish spawning and consequently the distribution of eggs and fry. In addition, fry procurement is influenced by the techniques of fry gathering and the degree of water pollution in the coastal areas.

There is an important relationship between techniques of fry gathering and fry procurement, and this relationship has great historical significance (Chen 1952; Lin and Chen 1980). Fry gathering can be increased by gear improvement. There are a number of different methods used to catch fry, ranging from the simple hand-operating scoop nets and sweepers that can easily be handed by one person to motorized rafts and boats (Table 1).

Variation in Fry Procurement

Fluctuations occur from year to year in fry supply, for instance, during 1965–79, the catch varied from a low of 33.96 million (1967) to a high of 234.87 million (1970). Since 1970, fry procurement has decreased year by year, reaching 61.85 million in 1979 (Taiwan Fisheries Yearbook).

The trend in fry procurement can be represented by regression equations for the years 1965–79 and 1970–79. On average, the trends for fry procurement over the two periods were:

$$Q = 143957.88 - 3005.34\,t;\ (1965\text{–}79),\ R^2 = 0.2660$$
$$Q = 202063.93 - 14309.72\,t;\ (1970\text{–}79),\ R^2 = 0.8284$$

Table 1. Fry gathering techniques.

Gear	Years used	Cost (N.T.$)[a]	Fry caught per day
Sweeper	3	1500	150-200
Fixed net	2	700	300-400
Motor rafts	7	45000	1500-2000
Boat	10	200000	3000-4000

[a]N.T.$36 = U.S.$1.00.

where Q stands for the quantity of fry caught and t shows the number of years. This means that the number of fry caught decreased annually by 3005 and 14310 thousand pieces during these periods.

In addition to annual fluctuations, the number of fry caught for a given level of effort varies from day to day and from month to month. Peak procuring days occur at the times of high tides associated with full and new moons, and the peak months are May and June. Taiwanese fry procurement is characterized by extreme seasonality reflected in marked peaks and slack periods. The index of seasonal variation reached 578.03% and the standard deviation of seasonal variation was 120.90.

Marketing and Distribution of Fry

Fry marketing and distribution are the core of the procurement subsystem and involve methods of transportation, marketing channels, marketing margins, regional distribution, and price variation.

Methods of Transportation

As a general rule, the transport route for fry is short and usually involves only three transactions: from gatherers to middlemen; middlemen to dealers; and dealers to milkfish and baitfish rearing ponds.

The main methods used to transport fry from the fry catchers to the middlemen are bicycle (75%), walking (16%), and motorcycle (9%) and the distances of the fry middlemen from the seashore are short (average 4.8 km). The most common type of transaction is for the middlemen to go to the seashore where the fry are stored temporarily by fry gatherers (75%), but 14% of the middlemen go to the fry gatherer's house, and 11% of fry gatherers deliver their fry to the middlemen.

Short distances are also involved between the fry middlemen and dealers, and the fry are transported by taxi (55%), motorcycle (27%), truck (9%), and by train (9%). Transportation costs depend on the distance and transportation facility used, but average transportation costs per

10 000 pieces are N.T.$188 (N.T.$36 = U.S.$1.00) with a 98% survival rate.

The last phase involves moving the fry from the dealers to the milkfish-bait rearing ponds and market-size milkfish rearing ponds. Traditionally, the fishpond operators go to the dealers to buy the fry and handle transport themselves. Fry are most commonly transported by motorcycle and truck depending on the distance and the quantity of fry purchased.

Marketing Channels and Marketing Margins

Accurate data on imported milkfish fry are very difficult to assemble; therefore this study only focuses on domestic fry. The marketing channels for fry can be divided into two phases: (1) before the middlemen phase — where 100% of fry pass from the fry gatherers to middlemen; and (2) after middlemen. After the middlemen, the method of distribution is diversified: 3% are transported from middlemen to market-size rearing ponds; 92% go to fry dealers; and 5% move directly to baitfish rearing ponds. Finally, the dealers distribute their fry to market-size milkfish rearing ponds (58%), overwintered fry nursery ponds (23%), and baitfish rearing ponds (19%).

Because the marketing channels for fry are short, the marketing margins are also small. The prices per fry received by fry gatherers and dealers were N.T.$2.03 to N.T.$2.55, respectively.

Distribution of Fry

Fry mostly come from the eastern part of this island where the resources of fry are plentiful but milkfish rearing facilities are very limited. Because the milkfish rearing areas are centred on the southwest part of Taiwan, the distribution of fry is, therefore, focused on this part of the island.

Tainan city is considered the fry trading centre. Most of the fry come from the eastern (66%) and southern coast (31%). The primary demand for fry comes from the Tainan area: 44% of the fry go to Tainan Hsien, 24% to Tainan city, 14% to Chai-I Hsien, and 11% to Kaohsiung Hsien.

Price Analysis of Fry

The price of fry is determined by supply and demand. The demand for milkfish is relatively stable because the total milkfish production area has remained unchanged during the past decades; the price of fry is primarily influenced by supply. As the quantity of fry increases, the price of fry decreases. This relationship between the price of fry and supply can be represented by a regression equation for the years 1965–79:

$$P_f = 5.0849 - 1.1008\ Q_f;\ R^2 = 0.6299,$$
$$\text{t-value} = 5.2161$$

where P_f stands for the price of fry (in real terms) and Q_f shows the quantity of fry caught. This equation indicates that the supply of fry is the main factor affecting their price.

To determine the long-term trend of fry prices, the least squares method was used to calculate the regression equations. The trends of fry prices are as follows:

$$P = 0.6987 + 0.0618\ t\ (1965\text{–}79)$$
$$R^2 = 0.5028\ \text{(current price)}$$
$$P = 2.5631 - 0.0941\ t\ (1965\text{–}79)$$
$$R^2 = 0.4254\ \text{(constant price)}$$

and

$$P = 0.1940 + 0.1862\ t\ (1970\text{–}79)$$
$$R^2 = 0.9902\ \text{(current price)}$$
$$P = 0.9720 + 0.0751\ t\ (1970\text{–}79)$$
$$R^2 = 0.6683\ \text{(constant price)}$$

where P stands for the price of fry and t is the number of years. This means that the price of fry has annually increased in terms of current price and annually decreased in terms of constant price during 1965–79. But during the last decade, the fry price has increased annually in terms of both current and constant prices. The seasonal variation in fry price is high because fry gathering is characterized by extreme seasonality. The total range of seasonal variation in the price of fry reached 200% and the standard deviation of the seasonal index was 52.02.

The price stability of fry can be computed using the Michaely Index and Von-Neumann ratio. The indices of instability of fry price (at current price) as measured by the Michaely index during 1965–79 and 1970–79 were 47.7% and 38.6%, respectively, which indicates extreme instability. In terms of constant price, the indices of instability were 28.1% and 17.6%, respectively, for the same periods, which indicates extreme instability and substantial instability.

In comparative terms, the regularity of fluctuation in the fry price, as measured by the Von-Neumann ratio, is modest and directional. During the periods 1965–79 and 1970–79, in terms of current prices, the Von-Neumann ratios were 1.25 and 2.01, respectively, whereas, in terms of constant prices, the ratios decreased sharply to 0.21 and 1.01, respectively.

An evaluation of this procurement subsystem must consider two points: (1) the stability of fry gathering — if the fry supply fluctuates, the price variation is high; and (2) an analysis of baitfish and market-size milkfish production because fluctuations in the price of fry may reflect price instabilities in baitfish and market-size milkfish.

Production of Milkfish Fingerlings for Baitfish Industry

Many factors, such as the demand for milkfish fingerlings for the deep-sea tuna fishing industry, the production environment of milkfish, and the relative profitability of market-size milkfish and milkfish-bait rearings, affect the rearing of milkfish fingerlings.

The rearing of fingerlings depends on a favourable rearing environment and a supply of new fry caught from the sea from early April to September. There are three periods for fingerling rearing during the year: (1) in early April for harvest before the end of May; (2) in early June for harvest within 60 days; and (3) in early August for harvest at the end of October (about 90 days are required because the weather is cooler and the fry grow more slowly).

Resource Use of Baitfish Farms

Baitfish rearing is a capital-intensive, labour-saving industry: on average, the land input per farm is 1.8 ha; the capital input per hectare is N.T.$114 703, and the labour input per hectare is 86 man-days. Capital inputs per hectare increase and labour inputs per hectare decrease as farm size increases. For farms of less than 1 ha the average direct capital investment is N.T.$111 141 and the labour input is 96 man-days. The figures for farms larger than 1 ha are N.T.$115 516 and 80 man-days.

The relationship between farm size and stocking rate per hectare for baitfish rearing is very significant. For farms under 1 ha, the stocking rate of fingerling per hectare is 37 091; for farms over 1 ha, the stocking rate of fingerling reaches to 41 621 pieces per hectare. The survival rates are 96% for farms under 1 ha and 92% for those larger than 1 ha.

Economic Analysis of Baitfish Farms

Baitfish rearing in Taiwan has significantly affected: (1) the benefit-cost ratio and rate of farm income; and (2) the factor productivity and elasticity of substitution.

Benefit-Cost Ratio and Rate of Farm Income

Milkfish fingerling rearing increases overall agricultural output and family farm income. Table 2 shows the benefit-cost ratio and the rate of farm income of different size baitfish farms in Taiwan. It is very difficult to estimate total family farm income, including off-farm income, because the extent of off-farm income depends on how many members of the farm family work outside the farm.

From the point of view of farm income, the B-C ratio is highly related to the size of the baitfish farm. Farms under 1 ha have lower farm income than larger farms. The rate of farm income increases with an increase in the size of the fingerling rearing farm. The rate of farm income was 27.79 for farms under 1 ha and 30.42 for farms over 1 ha.

Factor Productivity and Elasticity of Substitution

Baitfish rearing showed a significant relationship with factor productivity, which varied with farm size. Data from southern Taiwan (1979) indicate that the productivity of different size baitfish farms is closely related to land productivity, capital productivity, and labour productivity (Table 3). Factor productivity per hectare increased considerably with the adoption of intensive agricultural operations, such as capital intensive inputs and new rearing technologies.

The factor productivity of baitfish farms has advanced remarkably due to two major factors: (1) the increase of production per hectare; and (2) the price of baitfish compared with market-size milkfish. Factor productivities are usually considered as important indicators of the level of economic efficiency of production of small farms

Table 2. The benefit-cost ratio and rate of farm income per hectare for baitfish farms.

Farm size (ha)	(1) Farm receipts (N.T.$)	(2) Production costs (N.T.$)	(3) Farm income (N.T.$)[a]	Farm income/ production costs[b]	Rate of farm income[c]
< 1	162770	117531	45239	0.38	27.79
> 1	174097	121143	52954	0.44	30.42
Average	172153	120440	51712	0.43	30.04

[a]Equals column 1 minus column 2.
[b]Equals column 3 divided by column 2.
[c]Equals column 3 divided by column 1 times 100.

in Taiwan. One important implication of this analysis is that milkfish fingerlings for the baitfish industry have made a remarkable contribution to the growth of land, capital, and labour productivities. Hence, policymakers should place more attention on how this type of farming enterprise can be more effectively promoted within the milkfish sector.

The static CES production function was used to determine the elasticity of substitution of production on baitfish farms. The equation was estimated by ordinary least squares regression based on cross-sectional data from the farm survey (Table 4).

Based on the estimated parameters of the CES production function of baitfish farms, it is clear that the effect of technology (γ) on the production of baitfish farms was significant. With relative increases in capital inputs and relative decreases in labour inputs, capital was a significant substitute for labour, and labour-saving technology has been utilized in the baitfish farms.

The elasticity of substitution between capital and labour in baitfish farms was high (Table 4). On average, the value of elasticity of substitution was greater than one because capital input is growing more rapidly than labour input in this type of farming.

Table 3. Productivity and factor-factor ratio of baitfish farms.

	Farm size (ha)		
	< 1	> 1	Average
Per labour capital input C/N (N.T.$/man-day)	1120	1509	1398
Per capital labour input N/C (man-day/N.T.$)	0.000820	0.000663	0.000716
Per capital land input D/C (ha/N.T.$)	0.000009	0.000008	0.000008
Per land capital input C/D (N.T.$/ha)	117531	121143	120440
Per labour land input D/N (ha/man-day)	0.010378	0.012460	0.011605
Per land labour input N/D (man-day/ha)	96.36	80.26	86.17
Land productivity Q/D (N.T.$/ha)	162770	174401	172152
Labour productivity Q/N (N.T.$/ha)	1689	2169	1998
Capital productivity Q/C (N.T.$/N.T.$)	1.38	1.44	1.43

Table 4. Results of estimation of CES production function and estimated parameters for baitfish farms.

	Farm size (ha)		
	< 1	> 1	Average
β_1	2.8358	3.5711	2.7845
β_2	0.1095	0.6961	0.2635
	(6.0180)*	(0.1358)*	(0.3044)
β_3	0.6998	0.2912	0.6223
	(0.3710)	(5.7405)*	(0.6932)
β_4	9.2204	3.6017	1.4067
	(7.5015)*	(0.1172)	(0.2431)
F	54.2665	396.5886	295.7764
R^2	0.9585	0.9876	0.9715
n	11	25	36
γ	17.0442	35.5555	16.1914
k	0.1353	0.7051	0.2975
v	0.8092	0.9873	0.8858
ρ	−0.1948	−0.3509	−0.1520
σ	1.2419	1.5405	1.1793
R^2	0.9585	0.9876	0.9715
S	0.1293	3.5863	7.6406

Note: An asterisk denotes significance at 95% confidence level, numbers within parentheses are t-values, and number of farm households equals n.

Marketing Channels and Marketing Costs of Baitfish

The marketing channels are very short for milkfish used as baitfish. Baitfish producers buy fry from fry dealers. The fry, after being stocked in the nursery ponds for 60–90 days, become fingerlings that are suitable as baitfish for tuna long-liners. Some of the fingerlings are sold to market-size milkfish producers (about 35% of the total) because of the decline in demand for milkfish as bait for deep-sea fishing in recent years.

In 1979, marketing costs for 100 pieces of milkfish-bait were N.T.$198. Of this total, the profit of the middlemen accounted for about 51% of the total marketing cost. Salaries accounted for 12%, transportation 15%, oxygen 5%, losses 8%, and other expenses 9%.

Production of Market-Size Milkfish: Transformation Subsystem

Market-size milkfish rearing is considered as a subsystem that transforms milkfish fry to market-size fish. The milkfish industry, its resource use, and the input-output relationship of milkfish farms are briefly explained in this section.

Overview of the Milkfish Industry

Milkfish production is centred in the southern coastal areas of Taiwan. Production is entirely in the private sector, largely individual milkfish farmers whose ponds range from under 1 ha to 20 ha. A small number of companies are involved in milkfish production and their farms are larger than 50 ha.

The total production area in the past 15 years has shown a slight decrease from 15 616 ha in 1965 to 15 346 ha in 1979. Total milkfish production has been stable between 27 000 and 32 000 t/year from 1965 to 1979 although the annual fry catch has varied from 34 million to 235 million during the same years. Annual milkfish production per hectare increased from 1765 kg in 1965 to 2087 kg in 1979.

Not only is milkfish production influenced by the relative profitability of milkfish-bait rearing, it is also affected by the relative yields per hectare of other freshwater fish. The area devoted to milkfish production compared with the total aquaculture area has decreased from 41% in 1965 to 25% in 1979, while the production of other species has increased from 59% to 75% in the same period.

Resource Use of Milkfish Farms

For relatively small farms with large inputs of working capital, the relative importance of land in milkfish production has gradually decreased. Working capital is the major factor substituting for land in the expansion of milkfish production.

In 1979, the land input for milkfish farms ranged from 1.82 ha for farms below 3 ha, to 5.75 ha for farms between 3 and 10 ha, to 25.64 ha for farms above 10 ha. The average land input was 10.61 ha. The capital inputs of milkfish production consisted of 91% in direct costs and 9% in indirect costs. On average, the total capital inputs per hectare were N.T.$92 546. Labour inputs per hectare decreased relative to farm size from 117 man-days for farms of below 3 ha, to 84 man-days for farms between and 3 and 10 ha, to 71 man-days for farms above 10 ha. This trend was very significant.

Economic Analysis of Milkfish Production

Benefit–Cost Ratio and Rate of Farm Income

The benefit–cost ratio and rate of farm income for market-size milkfish farms are closely related to farm size (Table 5). This means that the large farms practice more effective farming, which results in higher farm income per hectare. The B–C ratio and rate of farm income increased as farm sizes grew, mainly because of smaller labour inputs per hectare and increased efficiency of capital and labour in the larger milkfish farms. Therefore, larger farms are useful because farmers can take advantage of technological change in combination with reduced labour inputs.

In comparing Tables 2 and 5, which show the B–C ratio and rate of farm income in baitfish and market-size milkfish farms, it is clear that production of milkfish fingerlings for the baitfish industry is more profitable and efficient than production of market-size milkfish. On average, the B–C ratio and rate of farm income for baitfish rearing are 0.43 and 30.04, respectively, whereas for production of market-size milkfish these figures are only 0.10 and 9.28, respectively.

Factor Productivity and Elasticity of Substitution

The productivity of a factor depends not only on the quantity of specific factor employed but also on the quantities of other resources used. Table 6 compares the factor productivities for different size milkfish farms. It is significant that the factor productivities are closely related to farm size. For instance, land productivity per

Table 5. Benefit–cost ratio and rate of farm income of milkfish farms.

Farm size (ha)	(1) Farm receipts (N.T.$)	(2) Production costs (N.T.$)	(3) Farm income (N.T.$)[a]	Farm income/ production costs[b]	Rate of farm income[c]
< 3	96625	91431	5194	0.0568	5.38
3–10	99886	92487	7399	0.0800	7.41
> 10	103195	92675	10520	0.1135	10.19
Average	102053	92546	9475	0.1024	9.28

[a]Equals column 1 minus column 2.
[b]Equals column 3 divided by column 2.
[c]Equals column 3 divided by column 1 times 100.

hectare ranged from N.T.$96 625 for farms below 3 ha, to N.T.$99 886 for farms between 3 and 10 ha, to N.T.$103 195 for farms above 10 ha. This increasing trend was very clear.

When compared with Table 3, it can be seen that the factor productivities are much higher in baitfish farms than in farms that produce market-size milkfish. If the purpose of using the milkfish resource is to maintain adequate resource returns and farm income in the face of growing competition from other freshwater fish rearings, a change from milkfish rearing to baitfish rearings, if the production environments are suitable, is necessary for increased productivity and efficiency of production. Capital inputs play a very important role in milkfish production; thus, analysis of the capital inputs and elasticity of substitution between capital and labour in milkfish farming is useful for examining resource use and technological change in milkfish production. The elasticities of substitution are shown in Table 7, which is based on the CES production function.

Table 6: Productivity and factor-factor ratio of milkfish farms.

	Farm size (ha)			
	< 3	3–10	> 10	Average
Per labour capital input C/N (N.T.$/man-day)	779	1106	1305	1218
Per capital labour input N/C (man-day/N.T.$)	0.00128	0.00090	0.00077	0.00082
Per capital land input D/C (ha/N.T.$)	0.000011	0.000011	0.000011	0.000011
Per land capital input C/D (N.T.$/ha)	91431	92487	92675	92546
Per labour land input D/N (ha/man-day)	0.00852	0.01196	0.01409	0.01316
Per land labour input N/D (man-day/ha)	117.41	83.62	71.00	75.98
Land productivity Q/D (N.T.$/ha)	96625	99886	103195	102053
Labour productivity Q/N (N.T.$/man-day)	823	1195	1454	1343
Capital productivity Q/C (N.T.$/N.T.$)	1.0568	1.0800	1.1151	1.1027

Table 7. Results of estimation of CES production function and estimated parameters of milkfish farms.

	Farm size (ha)			
	< 3	3–10	> 10	Average
β_1	2.6376	3.1691	2.5641	2.9078
β_2	0.5288	0.6793	0.7742	0.7660
	(1.2202)	(1.1070)	(1.0507)	(1.1968)
β_3	0.4051	0.1659	0.1216	0.0170
	(0.2829)	(0.0261)	(1.0079)	(1.0044)
β_4	0.0234	-0.0019	-0.0070	-0.0033
	(0.1752)	(-1.0042)	(-0.9065)	(-0.9120)
F	143.7766	56.6120	64.6766	171.6590
R^2	0.9664	0.8457	0.9023	0.8788
n	19	45	31	95
γ	13.9797	23.7871	12.9883	18.3165
k	0.4337	0.8037	0.1358	0.6783
v	0.9339	0.8452	0.8958	0.7830
ρ	-0.2037	0.0286	0.1340	0.3998
σ	1.2556	0.9722	0.8818	0.7144
R^2	0.9664	0.8457	0.9023	0.8788
S	0.0830	0.0586	0.0643	0.0573

Note: Numbers within parentheses are t-values and number of farm households equals n.

The high elasticity of substitution between capital and labour in milkfish farming is primarily for farms under 3 ha, for which the value of elasticity of substitution (σ) is greater than one. The values of elasticity of substitution are less than one for the other two farm sizes.

Marketing of Market-Size Milkfish: Delivery Subsystem

Marketing of milkfish is considered as a delivery subsystem of the milkfish industry. The milkfish produced in Taiwan are consumed fresh; therefore, the analysis of milkfish marketing will centre on marketing channels, marketing margins, marketing costs, and price variations of fresh milkfish.

Marketing Channels and Marketing Margins

There are three major marketing channels that provide the link between producers and consumers:

(1) Producers → wholesalers → city fish markets → dealer-retailers → retailers → consumers.

(2) Producers → cooperatives → city fish markets → dealer-retailers → retailers → consumers.

(3) Producers → dealers → dealer-retailers → retailers → consumers.

Milkfish farmers sell 71% of their products to wholesalers, 15% to cooperatives, and 14% to dealers. Thus, the wholesalers play a very important role in milkfish marketing.

The farm-retail marketing margins show the share of the consumer's dollars going to each intermediary. Producers received 74% of the retail price, with the remaining 26% being absorbed in the marketing process. The wholesaler and retailer receive 79% and 89% of the city retail prices, respectively.

Table 8 compares the wholesale farm prices and retail city prices, which can be used to calculate the producer's share of the retail price during the period 1970–80. The producer's share of the retail price has generally decreased annually. This share was 81% in 1970, increased to 98% in 1972, decreased to 59% in 1978, which was the lowest share during the last decade, and then rose above 70% in the years 1979 and 1980. On the contrary, the marketing group's share rose from 19% in 1970 to 29% in 1980. The difference between the wholesale price of production and the retail price rose from N.T.$5.26/kg in 1970 to N.T.$32.86/kg in 1980, a trend that was very significant.

Marketing Costs

The average total marketing cost per 100 kg was assumed to provide a rough approximation of the efficiency of milkfish marketing. This assumption can only be verified using time-series data to compare marketing costs over previous years, but unfortunately, there are no available time-series data to support or contradict this assumption. Therefore, in this case the costs of marketing can only be analyzed using expenses.

Table 9 shows the marketing costs of milkfish in Taiwan. The total marketing costs per 100 kg were N.T.$2755 and the proportion of marketing costs to retail price of milkfish was 26%. Among

Table 8. Farm price and retail price (N.T.$/kg) of milkfish.

	(1) Wholesale price of production	(2) Retail price in cities	Difference in prices[a]	Producer's share[b]
1970	22.68	27.94	5.26	81.17
1971	25.61	31.46	5.85	81.40
1972	33.06	33.68	0.62	98.16
1973	32.11	37.34	5.23	85.99
1974	48.63	52.32	3.69	92.95
1975	37.87	63.32	25.45	59.81
1976	43.47	68.78	25.31	63.20
1977	49.34	82.81	33.47	59.58
1978	55.67	94.05	38.38	59.19
1979	77.05	104.60	27.55	73.66
1980	80.82	113.68	32.86	71.09

[a]Equals column 2 minus column 1.
[b]Equals column 1 divided by column 2 times 100.
Source: Taiwan Fisheries Yearbook.

the cost items, profits, market management and taxes, and freeze, package, and transportation costs were 48%, 17%, and 17% of total costs, respectively. Profits, therefore, account for the highest percentage of the costs incurred in marketing.

The marketing costs of milkfish in Taiwan can also be illustrated by the marketing costs of the different marketing agencies. The major marketing agencies of milkfish are dealers, wholesalers, and cooperatives. As shown in Table 10, the total marketing costs per 100 kg were N.T.$601, N.T.$907, and N.T.$723 from the dealers, wholesalers, and cooperatives, respectively. Dealers are considered as the lowest cost incurred in marketing. Because the dealers transport fish directly to dealer-retailers or retailers, there are no taxes, market management, and fisherman insurance fees during the marketing process.

Table 9. Marketing costs per 100 kg of milkfish by expenses.

	Marketing costs (N.T.$)	Percentage of marketing costs
Market management	269	9.78
Taxes	199	7.24
Fisherman insurance	111	4.04
Freeze	113	4.10
Package	143	5.20
Transportation	214	7.78
Miscellaneous expenses	372	13.50
Profits	1332	48.36
Total	2755	100

Note: Percentage of marketing costs based on Lin and Chen (1980).

Price Analysis of Milkfish

It is possible to explain the price variation of milkfish in the long-run by seasonal variations and price instability. The least squares method can be used to compute the regression equation for the period 1970–80. The trends in milkfish price are:

Current Price

Wholesale farm prices $P_1 = 13.6547 + 5.3957\,t;\ R^2 = 0.9329$

Retail city prices $P_2 = 9.4507 + 9.1815\,t;\ R^2 = 0.9865$

Constant Price

Wholesale farm prices $P_1 = 51.0833 + 0.1245\,t;\ R^2 = 0.4478$

Retail city prices $P_2 = 47.3238 + 3.2216\,t;\ R^2 = 0.9171$

where P is the price of milkfish and t is the number of years. From these equations, the prices of milkfish, whether in wholesale farm prices or retail prices, increased annually at both current and constant price. The seasonal variation in milkfish price was high because milkfish production is characterized by substantial seasonality. The total range of the indices of seasonal variation of milkfish price was 89% and 115% of the wholesale farm prices and retail city prices, respectively. This shows that the seasonal

Table 10. Marketing costs for 100 kg of milkfish by different agencies.

	Dealer		Wholesaler		Cooperative	
	N.T.$	%	N.T.$	%	N.T.$	%
Salary	76	12.65	80	8.82	67	9.27
Transportation	125	20.80	124	13.67	173	23.93
Freeze	75	12.48	75	8.27	104	14.38
Package	38	6.32	38	4.19	57	7.88
Profit	260	43.26	218	24.04	—	—
Taxes	—	—	70	7.72	33	4.56
Market management	—	—	175	19.29	167	23.10
Fisherman insurance	—	—	91	10.03	87	12.03
Other expenses	27	4.49	36	3.97	35	4.85
Interest	20	3.33	19	2.10	7	0.97
Equipment depreciation	—	—	—	—	3	0.42
Water	—	—	—	—	1	0.14
Electricity	—	—	—	—	6	0.83
Fishery development funds	—	—	11	1.21	10	1.38
Mail and telegram	7	1.16	6	0.66	8	1.11
Total	601	100.00	907	100.00	723	100.00

variation of milkfish price is higher in retail city prices than in wholesale farm prices.

To measure the price instability of milkfish, the Michaely index and Von-Neumann ratio were adopted to compute the price data from wholesale farm prices and retail city prices at both current price and constant price. At current prices, the wholesale farm prices and retail city prices showed substantial instability (16.44 and 16.16, respectively), but in terms of constant prices both showed slight instability (6.42 and 5.91, respectively). With respect to the direction of change in price and regularity of variation, the milkfish price showed modest and directional variation (the values of the Von-Neumann ratio ranged from zero to one).

Finally, comparisons between the price of other fish and milkfish are required because milkfish is considered as a substitute for other fish. The trend in the freshwater fish–milkfish price ratio from 1965 to 1979 has decreased annually, except for shrimp where the price has increased annually faster than that of the milkfish. For example, the tilapia–milkfish price ratio decreased from 45% in 1965 to 42% in 1979 and the silver carp–milkfish price ratio decreased sharply from 82% to 37% in the same period.

The price ratio of milkfish to other freshwater fish has increased annually during the past 15 years because milkfish is considered a good fish in Taiwan. Nevertheless, the relative importance of milkfish in terms of production area relative to the total aquaculture area has been decreased from 41% in 1965 to 25% in 1979. This is because freshwater fish farms have adopted new fishpond management and rearing technology and the yield per hectare in these farms is higher than in milkfish production.

Policy Implications

As economic growth quickens and per-capita income increases in Taiwan, the demand for aquatic products increases. As a result, the aquaculture area has expanded rapidly during the past 15 years. However, the milkfish production area has remained at about 15 000 ha, and yields per hectare have increased slowly compared with other freshwater fish species. The revenue per hectare is also lower for milkfish production than for other freshwater fishes. Under such conditions, the growth in milkfish production has slowed. Improvement of fishpond management and the use of the new rearing technology are essential to avoid such inefficiencies in production and to increase the income of producers. However, because the milkfish resource system consists of three subsystems, procurement, transformation, and delivery, any suggestions for improvement should cover all three subsystems.

- *Procurement subsystem:* The main problems of this subsystem are the supply of fry and their price. To increase and maintain the source of milkfish fry and stabilize fry price, our efforts must emphasize: (1) the control of water pollution in coastal areas; (2) the improvement of fry gathering techniques: and (3) the development of artificial spawnings of milkfish fry.
- *Transformation subsystem:* A good resource system should provide flexibility for the adjustment of farm management in response to changes in economic and technological conditions. For economies of scale and production efficiency, the farmers should be encouraged to participate in group farming and contract farming to broaden their base of operations and to increase yields per hectare by adopting new rearing technology such as deep-water systems. This will allow them to meet the needs of dynamic economic and technological situations.
- *Delivery subsystem:* In 1979, the milkfish shipped to city markets through cooperative marketing by the Fisherman's Association accounted for only 15% of total milkfish production. Under cooperative marketing, fish products are collected and directly transported to market by the Fisherman's Association. In this way, some marketing costs can be saved and the producer's income can be increased. Therefore, cooperative marketing of milkfish could be an excellent system for increasing marketing efficiency and producer's income.

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Discussion

The demand for fish is rising in Taiwan, but the benefits are not going to milkfish production. Is this due to marketing problems or biological constraints to improving the technology in milkfish culture? Shrimp and crab production is more profitable in Taiwan than milkfish, and farmers are switching from milkfish. In this case, marketing research should proceed along with biological research.

Questions were raised concerning the ways of substituting labour for capital in milkfish culture. One could, for example, dispense feed by hand rather than a feed hopper.

How can the interaction between the different inputs in milkfish production be captured? One could do this rather easily by estimating a translog production function. At the same time, biologists could try to pinpoint the physical nature of these interactions.

General Discussion

The general discussion on all three case studies revolved around the question of deriving possible generalizations such as: Which biological parameters are going to change profitability? Use of broken rice as feed and decreasing the feeding of trash fish were among the parameters mentioned in the case of Thailand. However, any answer in terms of numbers must await studies by biologists on the precise relationship between these parameters and yield.

One discussant thought that economists were assuming more than what even the biologists know. For example, are algae the real food of the fish or are bacteria the actual food? It was pointed out that, in the case of traditional practices, economists could identify the areas of knowledge that biologists should probe, whereas, in the case of the new practices (e.g., cage culture), biological research should precede economic analysis.

The research conducted by biologists can help expand the present set of production methods, i.e., add points to the isoquant; whereas, technical progress helps to move the isoquant inward. Biologists could team up with economists to take account of environmental factors, like pH, salinity, and algae content, in production function analysis.

A further general observation was that neither biological or economic parameters remain static. Therefore, when an economist's production function analysis suggests a change in the ratio of the quantity of factor inputs, it must be assumed that as a result of that change, changes will occur in the biological environment that may affect productivity in a way not accounted for in the original production function analysis. Conversely, a biological recommendation on the use of a production factor input to increase yield may cause a change in the future cost or value of both the input and output. Therefore, the original economic viability of that change must be reassessed. It is essential that a continuous dialogue be established between economists and biologists during the process of problem identification and research.

Session II
Microeconomic Analysis of Experimental Production Systems

Microeconomic Analysis of Experimental Aquaculture Projects: Basic Concepts and Definitions

Yung C. Shang[1]

The main objectives of this paper are to outline: (1) the basic biotechnical means that can be used to increase production of a given area, which relate to inputs and costs; (2) the components of biotechnical development that should be subject to economic analysis; and (3) the basic economic tools for analysis of experimental projects (costs and return, partial budgeting, discounting method, sensitivity analysis, etc.).

Aquaculture has a rich history of several thousand years. But present technology has been developed largely by trial and error rather than by scientific research. The productivity of existing resources can be increased through systematic research with a consequent increase in profitability. It is this dynamic element of constant improvement that provided the key to the development of agriculture, and it will also hold true for aquaculture. Because aquaculture is a multidisciplinary science, which includes biology, engineering, nutrition and feed technology, genetics, economics, etc., a wide spectrum of interrelated research is required to develop an efficient system of operation and to improve existing management practices. Biotechnical research aims to improve production possibilities, while economic research improves the profitability of operation. Because most research in aquaculture is for the purpose of establishing a viable operation, economic research plays an important role in its development. It provides a basis for decision-making among farmers and for the formulation of a public aquaculture policy.

New technologies developed in the biotechnical fields must be subject to economic analysis before they are widely recommended to fish farmers to ensure that the farmers will benefit. Because environmental and socioeconomic conditions vary in different regions, a profitable technology in one region is no guarantee it will be successful in another region. Economic evaluations, therefore, should be done under local conditions. When such technologies are first developed, economic analysis must be based largely on "artificial" data from experimental or pilot operations.

Economic Analysis in Biotechnical Development

Much of the biotechnical research done in aquaculture aims to increase the productivity of a given water area. The productivity per unit of water area, from the biotechnical point of view, depends mainly on the stocking rate, the survival rate, and the average weight of the individual fish at the time of harvest (Fig. 1). Therefore, increasing the rates of stocking, survival, and growth are the primary means of increasing production.

One of the most important practices in aquaculture is the stocking of the right amount of fry or fingerlings to maximize production. A fishpond, for instance, can only support a certain quantity of fish because of its limited space and the amount of natural food available. This limit is usually called the "carrying capacity" and is affected mainly by soil conditions and the water quality of the pond. The carrying capacity of a pond can be partially increased by fertilization and/or supplemental feeding. The purpose of fertilization is to increase the production of plankton (in freshwater ponds) or benthic algae (in brackish water ponds) as fish food, while supplemental feeding compensates for nutrients that are in short supply in the pond. The experiences of carp and milkfish culture in various countries indicate that fertilization and/or

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- Production per unit of water area
  - Stocking rate
    - Fertilization and/or feeding
    - Aeration or running water
    - Polyculture
    - Stock manipulation
      - • Mono size stocking
      - • Multiple size stocking
      - • Multi stage stocking
      - • Mono sex stocking
      - • Double cropping
  - Survival rate and growth rate
    - Good management practice
      - • Correct stocking densities
      - • Right kind and amount of food
      - • Proper water quality
      - • Prevention of diseases and parasites
      - • Elimination of predators

Fig. 1. Factors affecting the productivity of a given water area in aquaculture (after Shang 1981).

supplemental feeding increase the carrying capacity and, consequently, the production of a pond many times more than under natural conditions (van der Lingen 1959; Yashouv 1959; Tang 1970; Shang 1976; Hepher 1978). The total cost with fertilization and/or supplemental feeding is higher. Whether the cost per unit of output is lower and the additional revenue generated is higher than the additional cost involved in fertilization and feeding requires economic analysis. In addition, many kinds of feed and fertilizer can be used (vegetable and animal-originated feeds, and organic and inorganic fertilizers). The choice and combination of feed and fertilizer, as well as the quantity of application, depends mainly on their costs and effectiveness, which should be subject to an economic analysis. Economic analysis is also needed in the formulation of the least-expensive feed.

Aeration and running water systems usually increase the amount of dissolved oxygen and, therefore, increase the carrying capacity of a pond (Kawamoto 1957; Chiba 1965; Bardach et al. 1972). The economic feasibility of using these techniques depends on whether the additional revenues offset the additional costs.

The carrying capacity of a pond also can be increased by polyculture (stocking a number of species in the same pond) and stock manipulation (methods used to manage the fish population in the pond). A fishpond, especially a freshwater pond, usually produces a variety of food organisms in different layers of the water. Thus, the stocking of species that have complementary feeding habits or feed in different niches will effectively utilize the space and the food available in the pond and will therefore, increase total fish production. The selection and combination of species and their stocking ratio depends mainly on the compatability of the species, the availability of natural food, the availability and cost of fry (or fingerlings), and the prices of fish.

Several fish stocking practices of varying complexities have been used for various species in different regions: (1) monosize stocking (stocking of the same size fish in a pond and harvesting at marketable size); (2) multiple-size stocking (stocking of different age groups of fish in a pond with periodic harvesting and restocking); (3) multistage stocking (stocking uniform size fish in different sizes of ponds progressively when more space is needed); (4) monosex stocking (only male or female fish is stocked in a pond); and (5) double-cropping (stocking of two species in the same pond but in different seasons). The comparison and selection of stocking practices should be subject to economic analysis.

Increases in survival and growth rates are important factors in increasing production. This is mainly dependent on, in addition to the right stocking and feeding rates, the proper water quality, the prevention of diseases and parasites, and the elimination of predators and competitors. All these involve extra inputs and costs. The measures to be used and the levels of inputs to be applied should be subject to economic analysis.

Economic Analysis of Experimental Projects

Evaluation of a Particular Measure

Many of the previously mentioned measures to increase the productivity of a given water area can be developed as an experimental project. In most cases additional inputs and costs, e.g., labour and materials, are required. When one input is increased by equal increments per unit of time with other resources held constant, the resulting output may at first increase at an increasing rate, then at a diminishing rate, and finally decrease. This relationship is defined as the law of diminishing return. To determine the maximum level of input for profit maximization, marginal analysis is usually needed. Given a quantitative input and output relationship from the pilot operation, the cost of inputs and the price of outputs must be taken into consideration in determining the most profitable level of input. Profit will be maximized when the added revenue from the last unit of input (marginal value of product) equals the cost of that input (marginal input cost). In many cases, a given level of production can be produced by various combinations of inputs. For instance, to a certain degree, different types of fertilizer, feed, and pesticides are substitutable in aquaculture. The least-cost combination of inputs to produce a given level of output would occur when the marginal rate of substitution (the amount one input must be changed to offset a change in the amount of the other input to maintain a given level of production at lowest cost) equals the inverse ratio of marginal input prices (Shang 1981). As for polyculture, the profit maximizing combination of two or more species with given resources is achieved when the marginal rate of substitution equals the inverse ratio of their prices.

Comparison of Different Culture Techniques or Systems

When an experimental project is to compare the efficiency of different management systems or culture techniques, such as extensive versus intensive, monoculture versus polyculture, monosex versus mixed-sex culture, monosize versus multiple-size stocking, standing water versus running water, nonintegrated versus integrated operation, raft versus long-line culture, a cost-return analysis is usually necessary. In this case, detailed input and output data, both in quantitative and in value terms, from existing management practices and from ongoing experiments are needed. Various indicators can be calculated to compare the productivity of major inputs under different management systems (Shang 1981).

- Productivity (or value of production) per unit of major input, such as kg/ha, kg/man-hour, kg/unit of feed or fertilizer, kg/unit of capital. These indicators can be used to measure the efficiency of the operation in terms of resource utilization. However, they usually indicate the relationship of one input to one output without considering the quality and quantity of the other inputs.
- Amount (or cost) of input required per unit of output, such as $/kg, man-hour/kg, units of feed (or fertilizer)/kg. These are measures of capital intensity, labour intensity, and the feed conversion ratio, respectively. Again, these measures ignore the variation in quality and quantity of the other inputs. Net revenue: gross revenue less total costs.
- Profit: the difference between gross revenue and total operating cost of production.
- Return to labour: gross revenue less total costs except those associated with the operator's labour and management.
- Return to land: gross revenues less total costs except those associated with land costs.
- Return to capital: gross revenues less total costs except the opportunity costs of capital.
- Rate of return on capital investment: returns to capital divided by capital investment.
- Payback period: number of years required to recover the initial investment.
- Break-even analysis: the level of price or production at which the project just covers its total costs.

When there is a minor change in a production technique resulting in a partial change in cost-return structure, partial budgeting may be used to recalculate economic viability.

In considering a partial cost-return analysis, one must answer the following questions: (1) What costs will be added or increased if one proceeds with the venture? (Ignore the costs that will not be changed.) (2) What existing costs will be reduced or eliminated if one proceeds with the venture? (3) How much will the existing income or receipts be increased? What new receipts will there be? (Ignore receipts and income that will not change as a result of the venture.) (4) What income and receipts will be foregone if you proceed with the venture.

Once these calculations are completed, the sum of decreased costs (item 2) and increased receipts (item 3) should be subtracted from total increased costs (item 1) and decreased receipts (item 4). A positive result would mean that the change would be profitable. A negative result would mean that the change would not be profitable.

Feasibility of New Species and New Culture Techniques

For new species culture and new culture technology, such as cage culture, pen culture, raceway culture, raft culture, or integrated aquaculture-agriculture operations, an economic feasibility analysis should be conducted based on experimental data. The preliminary economic feasibility study is valuable because it provides gross indications of the ultimate profitability of the project and indicates, from an economic point of view, the areas that need more research for improvement. To estimate the preliminary profitability of a new production project, the cost-return method based on estimated annual average data may be used. The major limitation of this measure is that it fails to consider the timing of incomes and expenditures. In most investment processes in aquaculture a large amount of capital outlay is necessary at the initial stage of investment and the returns accrue to the investor over a period of time. A dollar in hand is more valuable than a dollar to be received sometime in the future. Therefore, the profitability of investment in a new and long-term project is more accurately measured by the discounting method, which converts future revenues and costs (for the analysis period) into present values. The traditional procedure of discounting is to estimate: (1) the amount and timing of capital costs (including replacement costs) over a period of years for analysis; (2) the annual operating costs for various inputs, taking into consideration inflation and relative price changes in the future; (3) the annual revenue based on expected yields and prices; and (4) the salvage value of the investment at the end of analysis period.

With the information listed above, annual profit can be calculated and discounted. Then the benefit-cost ratio and/or internal rate of return can be calculated. The former is defined as the ratio of the present value of benefits (or revenues) to the present value of costs, while the latter is the discount rate that makes the present value of the net cash inflow equal to zero, which is referred to as the average earning power of money used in the new investment project over the project's life. The discounting method used for evaluation of private investment is usually referred to as "financial analysis," and it concerns only the costs and returns to the investor. Investment made by the public sector based purely on business criteria is not sufficient. Investment should be analyzed from society's point of view, and this is usually referred to as "economic (or social) analysis." Social benefits and costs have a broader scope than private returns and costs because of the inclusion of both direct and indirect effects. For detailed procedures and methods of discounting techniques used in aquaculture, see Shang (1981).

A new investment project in aquaculture is usually subject to a certain degree of risk and uncertainty in the estimation of yields, costs, prices, etc. The data used in the financial and economic analysis are usually the best or most likely estimates of these important variables. It is, however, very important to the decision-makers to know what effect departures from these values will have on the project. Therefore, sensitivity analysis is often necessary, which is simply to recalculate economic viability under alternative sets of input-output prices and yields. The degree of departure from the original estimates to be used in the sensitivity analysis is a matter of judgment and depends on environmental, biological, and market situations. As the project progresses, old assumptions can be modified, new cost and price information can be acquired, and, therefore, the economic feasibility analysis can be updated.

For new species cultivation, it is important to include a market potential study as a part of the economic feasibility analysis. A species has the potential for commercial development only if there is a market demand for it at prices that provide a reasonable profit for the producers.

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An Analysis of the Economics of Farming Green Mussels in Singapore Using Rafts

L. Cheong[1] and W.S. Loy[2]

Raft culture of green mussels in Singapore is described and the economics of various operations are discussed. Operations using polycoco ropes on a single 150-m^2 raft and in farms of 0.5 and 0.75 ha size are shown to be economically feasible in Singapore. Labour constitutes the largest variable cost and sensitivity tests show that increases in labour cost have a greater impact on production cost than decreases in raft cost.

The green mussel, *Perna viridis* (Linnaeus), is found in considerable abundance at the intertidal and subtidal zones of the coastal waters along Johore Straits. The present supply is derived mainly from wild stocks harvested by artisanal fishermen during low tide. Production is low, about 250 t, and irregular because stocks are not managed and become depleted at times through overfishing.

The farming of mussels using the raft method employed in Spain was, therefore, tested by the Primary Production Department in late 1975. Culture ropes, upon which the mussels attach and grow, are suspended from rafts anchored at sea. However, unlike those used in Spain, where a rope could be as long as 12 m and a typical raft about 20-m square, i.e., 400 m^2 (Andreu 1968), local rafts are much smaller, below 150 m^2, and maximum rope length is 4 m (Cheong and Chen 1980). This suits local conditions because smaller rafts involve less capital and shorter rope lengths can be suspended within the eutrophic zone of 3.5–5.3 m.

Mussels were found to attain market size of 6–7 cm shell length within 6–7 months, and a production of 120 kg shell-on mussels/m^2 was obtained under raft culture (Chen 1977; Cheong and Chen 1980). Recognizing the great development potential of mussels as a protein-rich source of food in Southeast Asia, the Department conducted further studies on improving the technique employed, especially the elimination of thinning, which was identified as a major constraint to large-scale production. A culture rope, the polycoco rope, which incorporated both spat-catching and grow-out phases, was tested and found to perform well without thinning. Mean yields of 30.74 ± 6.07 kg and 56.37 ± 13.88 kg shell-on mussels per rope were obtained from 2-m and 4-m polycoco ropes, respectively, after 6 months' culture without thinning; whereas, plain 4-m polyethylene ropes that were thinned-on yielded 45.97 ± 6.04 kg shell-on mussels per rope at harvest (Cheong and Lee, in press).

This paper describes some of the economics involved in the production of mussels under the raft method of culture. Production figures are extrapolated from the above yields and calculations on cost and assessment of labour requirements are based on experience gained from mussel research studies conducted by the Department.

Culture Method

Raft Specifications

The rafts are basically wooden pontoons with cross beams for suspending the culture ropes. Raft size varies but in the studies 75 m^2 and 150 m^2 effective productive areas were used. The rafts were constructed in modules of 5 m × 5 m because the wooden beams came in maximum lengths of 6–7 m. A 75-m^2 raft measured 5 m × 15 m and a 150-m^2 raft 10 m × 15 m (internal dimensions). Plastic drums of 200 L capacity were previously used for floating the raft but were subsequently replaced by similar sized metal

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drums (used oil drums) as the latter were cheaper, S$14 as compared with S$60 per plastic drum (as of 1980, S$2.15 = U.S.$1.00), and more readily available in the market. In the past, shades made from the fronds of attap (*Nipa frutescens*) attached to wooden frames were placed on top of the raft. Under shaded conditions, spat distribution along the spat-collecting rope was more uniform. However, with the use of the polycoco rope, where the coconut pieces attached to the main polyethylene rope acted as spat settlement areas and served to distribute the spats over the entire rope length, shading was found to be unnecessary.

The rafts are either positioned singly or, as has been found more practical, in a row parallel to the flow of flood and ebb tides. The latter arrangement maximizes utilization of water space and reduces the problem of rope entanglement often encountered with individually anchored rafts. Concrete anchors are used for positioning the rafts.

Rope Specification

The past practice was to use two types of rope for culture, i.e., a nursery or spat-collecting rope made of nonoiled coconut coir fibres and a production rope made of polyethylene material. Both ropes were 4 m in length with a diameter of 40 mm for the nursery rope and 14 mm for the production rope. A piece of polyethylene rope 1.5-m long was provided at one end of the culture rope for tying. Short wooden pegs or chopsticks were inserted at 0.5 m intervals in the production rope to prevent mussel slippage during culture. The ropes were then suspended at a density of 4 ropes/m^2 in both cases.

Thinning was required 2 months after spats had collected on the nursery ropes. The operation was laborious and time-consuming; approximately 0.25 man-hours were required to prepare a single production rope. The process consisted of plucking out the spats from the nursery rope, laying them along the production rope, and finally binding the spats to the production rope with a cotton netting. After about 10–14 days, the cotton netting rotted away leaving the spats that had reattached themselves firmly to the new rope. The mussels were then cultured for a further 4–5 months after thinning.

Presently, a different culture rope incorporating both spat-catching and grow-out phases is used. The new rope, called polycoco rope, consists of a main 14-mm diameter polyethylene rope with pieces of 40-mm diameter coconut coir ropes attached to the middle of each metre of the main rope. The coconut coir pieces are 30 cm in length and either used or new coconut coir ropes can be used. The main polyethylene rope has either a 2-m or 4-m culture length and a 1.5-m length for tying. Because spats settle mainly on the coconut coir pieces, the coir serves as an area of spat collection and effectively distributes settlement over the entire rope length. During the grow-out phase, the mussels spread along the rope and, thus, eliminate the need for manual thinning.

Management

Culture ropes are immersed for spat collection in areas where spats are abundant. For operations involving thinning, the spats, collected on spat-collecting coconut coir ropes, must be thinned-out to production polyethylene ropes and either left in the spat-collecting grounds or in the production grounds for grow-out. With the use of polycoco ropes the entire rope laden with spats is used for the grow-out and no thinning is necessary. Mussels in either case are derived from the same spatfall and attain more or less the same size at harvest. After the harvest, the ropes can be reimmersed for another growing season so that two harvests per year are possible.

The holding capacity of the raft is limited by the buoyancy of the drums. Studies have shown that it is possible to hold ropes containing on-growing mussels and those containing spats on the same raft. In this way, the harvest can be continuous and with proper timing of rope immersion to spatfall, it is possible to have three harvests per year using two sets of ropes. This practice increases production and is especially suitable for areas with poor spatfall where spats must be collected elsewhere.

Production

In the present economic study, the reliable minimal estimate (RME) of yield at 95% confidence is used. Based on results obtained by Cheong and Lee (in press), the RME yields of 2-m and 4-m polycoco ropes are 25 kg and 42 kg, respectively; whereas, the usual 4-m polyethylene ropes requiring thinning yield 40 kg at harvest. For the sensitivity test the upper yield levels of the 4-m polycoco rope were used, these were: (1) a mean yield of 57.37 kg (or 60 kg); (2) a maximum yield (at 95% confidence) of 70.25 kg (or 70 kg); and (3) a maximum yield of one of the six ropes used in the study, i.e., 79.81 kg (or 80 kg).

Economic Considerations

Rafts

The various components of the 75-m^2 and 150-m^2 rafts are summarized in Table 1. The items are categorized under fixed capital cost for semipermanent fixtures, which are normally not replaced unless damaged during the course of culture, and variable capital cost for replaceable items, which are usually subject to wear and tear and corrosion. The former are expected to have a life of 5 years and annual depreciation is based on 20% of initial cost. The life expectancy of replaceable items varies from 0.5 to 1 year.

Labour costs are included in the overall costing as the construction and assembling of the rafts are assumed to be contracted out. Miscellaneous costs for electricity for operating electric drills and saws, and water for washing drums (floats) are also included. The initial cost of a 75-m^2 raft is approximately S$3111; a 150-m^2 raft is approximately S$5318. The annual depreciated costs are S$1637 and S$3109, respectively. Semipermanent fixtures constitute the main bulk of the cost of the raft (62–68%). However, the replaceable items comprise the main portion of the depreciated annual value (69–74%) with the major contributory factor being the replacement for floats and accessories (65–68%).

Culture Ropes

The comparative costs of various culture ropes are tabulated in Table 2. Four types of ropes are described: nursery or spat-collecting and production or grow-out ropes of 4-m length each and

Table 1. Summary of capital costs (S$) of 75-m^2 and 150-m^2 rafts based on 1980 prices (S$2.15 = U.S.$1.00).

	75-m^2 raft			150-m^2 raft		
	Initial cost (S$)	Life expectancy (years)	Depreciated annual cost (S$)	Initial cost (S$)	Life expectancy (years)	Depreciated annual cost (S$)
Fixed capital costs						
Wood						
Main frame	797.50	5	159.50	1595.00	5	319.00
Supporting beams ($7.35 each)	220.50	5	44.10	441.00	5	88.20
Planks ($10 each)	100.00	5	20.00	200.00	5	40.00
Lights and anchoring						
Navigational lamps ($66/set)	66.00	5	13.20	132.00	5	26.40
Concrete anchors (sand, gravel and cement)	120.40	5	24.08	120.40	5	24.08
Iron bar ($4/m)	64.00	5	12.80	64.00	5	12.80
Chain ($17/m)	136.00	5	27.20	136.00	5	27.20
Shackle ($18 each)	72.00	5	14.40	72.00	5	14.40
Thimble ($20 each)	80.00	5	16.00	80.00	5	16.00
Anchor rope ($450/160-m coil)	450.00	5	90.00	450.00	5	90.00
Total	2106.40 (68%)	—	421.28 (26%)	3290.40 (62%)	—	658.08 (21%)
Variable capital costs						
Bolts, nuts, nails and washers	73.01	1	73.01	165.22	1	165.22
Floats ($14/200-L drum)	448.00	0.5	896.00	896.00	0.5	1792.00
Paint	60.00	0.5	120.00	120.00	0.5	240.00
Twine ($11.75/coil)	23.50	0.5	47.00	47.00	0.5	94.00
Total	604.51 (19%)	—	1136.01 (59%)	1228.00 (23%)	—	2291.22 (74%)
Labour and miscellaneous costs						
Labour ($600/month)	300.00	5	60.00	600.00	5	120.00
Miscellaneous	100.00	5	20.00	200.00	5	40.00
Total	400.00 (13%)	—	80.00 (5%)	800.00 (15%)	—	160.00 (5%)
Total raft cost	3110.91	—	1637.29	5318.62	—	3109.30

Note: Percentage denotes portion of total raft cost.

Table 2. Comparative costs (S$) of various culture ropes based on 1980 prices (S$2.15 = U.S.$1.00).

	Thinning ropes (4-m)		Polycoco ropes	
	Nursery/spat collecting	Production/ grow-out	2-m	4-m
Material costs				
Polyethylene rope	0.61	2.23	1.43	2.23
Coconut coir rope	2.76	—	0.41	0.83
Polytex twine	0.06	0.06	0.06	0.06
Kuralon twine	0.04	—	0.07	0.14
Manila twine	0.08	—	—	—
Brick	0.09	—	—	—
Chopsticks	—	0.32	—	—
Total	3.64 (75%)	2.61 (77%)	1.97 (68%)	3.26 (72%)
Labour and miscellaneous costs				
Labour	1.19	0.71	0.89	1.19
Miscellaneous	0.05	0.05	0.05	0.05
Total	1.24 (25%)	0.76 (23%)	0.94 (32%)	1.24 (28%)
Total cost per rope	4.88	3.37	2.91	4.50

Note: Percentage denotes portion of total rope cost.

polycoco ropes 2-m and 4-m long. All ropes are treated as operating items with a life expectancy of 1 year. However, the coconut coir rope is usually subject to boring by *Toredos* when immersed in the sea and it is useful for only about 6 months, i.e., two spat-collecting immersions of 2–3 months per immersion. It must be carefully checked prior to every spat-collection operation when it is used as a nursery rope, otherwise whole portions of weakened sections may fall off when spat-laden. However, when it is attached as pieces to the main polyethylene rope, as in the case of the polycoco rope, the holes made by the *Toredo* borers do not matter because the weight of the spats that settle on the coconut coir rests on the main polyethylene rope. The polyethylene material used could actually last for more than a year although an expectancy of 1 year is used.

The construction of ropes is also assumed to be contracted out and, hence, labour costs are included in the cost of the rope. Miscellaneous costs for purchase of spirit for sealing polyethylene rope ends, matches for lighting the spirit, etc., are also included. A 4-m nursery rope costs S$4.88; a production rope of similar length costs S$3.37. Polycoco ropes 2-m and 4-m long cost S$2.91 and S$4.50, respectively. A culture method that involves thinning requires both nursery and production ropes and, depending on the spatfall at the time of immersion, one nursery rope can be thinned-out to about three production ropes. Nonthinning, however, only involves the use of a single type of rope, viz., a polycoco rope either 2-m or 4-m long, because both spat-catching and grow-out phases are incorporated on the same rope. The most expensive component of a nursery rope is the coconut coir portion (57% of cost); whereas, for the production rope and polycoco ropes, the polyethylene material is the expensive item (49–66%).

Culture Operation

Thinning and Nonthinning

The costs of raft culture operations involving thinning and nonthinning are tabulated in Table 3. Calculations are based on the operation of a single raft, either 75 m^2 or 150 m^2. For operations involving thinning, 4-m culture ropes are used; whereas, for nonthinning either 2-m or 4-m polycoco ropes are used. Because the first harvest is obtained after 6 months of culture, the working capital, as for subsequent calculations, is based on half a year and is obtained by dividing the annual variable cost by two.

For a single raft operation of either 75 m^2 or 150 m^2, only one worker is needed to operate and maintain the raft if thinning is not required. However, at least two workers are required to manage a 150-m^2 raft if thinning is done. This is because one worker would take at least 2 weeks to

Table 3. Comparative costs (S$) of thinning and nonthinning culture based on 1980 prices (S$2.15 = U.S.$1.00).

	Thinning		Nonthinning	
	75-m² raft	150-m² raft	75-m² raft	150-m² raft
Capital investment				
Fixed assets	6111	8818	6111	8818
Working capital	4375	8749	(a) 3837 (b) 4075	(a) 5273 (b) 5750
Total capital	10486	17567	(a) 9948 (b) 10189	(a) 14091 (b) 14568
Operating cost/year				
Fixed costs				
Depreciation	2237	3809	2237	3809
Licence fee	40	75	40	75
Cost of capital at 10% interest	1049	1757	(a) 995 (b) 1019	(a) 1409 (b) 1457
Total	3326	5641	(a) 3272 (b) 3296	(a) 5293 (b) 5341
Variable costs				
Staff salaries ($400/month)	4800	9600	4800	4800
Ropes, netting etc.	1949	3896	(a) 873 (b) 1350	(a) 1746 (b) 2700
Maintenance of boats and miscellaneous	500	1000	500	1000
Fuel and miscellaneous transport	1500	3000	1500	3000
Total operating costs	12075	23139	(a) 10945 (b) 11446	(a) 15839 (b) 16841
Annual returns				
Yield (tonnes) at two harvests per year	24.0	48.0	(a) 15.0 (b) 25.2	(a) 30.0 (b) 50.4
Cost of production (S$/tonne)	503	482	(a) 730 (b) 454	(a) 528 (b) 334
Return per S$ investment at sale price of S$350/tonne	0.70	0.73	(a) 0.48 (b) 0.77	(a) 0.66 (b) 1.05

Note: (a) is for 2-m polycoco rope; (b) is for 4-m polycoco rope.

produce the 300 thinned-on production ropes needed to stock a 75-m² raft and at least 1 month to produce the 600 needed for a 150-m² raft. During the long thinning period the mussels, which would have grown heavier, would tend to fall off.

The licence fee is based on S$500 per 0.5-ha farm and the effective productive area on 20% utilization of water space. The 75-m² and 150-m² rafts require 375 m² and 750 m² water space, respectively. The licence fee, therefore, works out to be about S$37.50 (say S$40) for a 75-m² farm and S$75 for a 150-m² farm.

Using one set of ropes, two harvests per year are possible based on a culture cycle of 6 months. Depreciation of the raft is based on the calculations in Table 1 and depreciation of other fixed assets, like boats and miscellaneous items, is based on a straight-line depreciation over 5 years.

The costs of production per tonne of mussels for an operation requiring thinning are S$503 and S$482 for the 75-m² and 150-m² raft operations, respectively. For operations that do not require thinning the cost of production using 2-m polycoco ropes are S$730 and S$528 for the 75-m² and 150-m² rafts, respectively. The use of 4-m polycoco ropes lowers the cost of operation to S$454 for a 75-m² raft and S$334 for a 150-m² raft.

Single Raft and Farm

The comparative costs of operating a single raft and a 0.5-ha farm using 4-m polycoco ropes are tablulated in Table 4. The total effective productive area of the farm, i.e, the area available for suspending the culture ropes, is based on a 20% utilization of the water space, that is 13 × 75-m² rafts or 7 × 150-m² rafts for a 0.5-ha farm. However, the effective productive area

Table 4. Comparative costs (S$) of operating a single raft and a 0.5-ha farm using 4-m polycoco ropes based on 1980 prices (S$2.15 = U.S.$1.00).

	Single raft		0.5-ha farm (at 20% utilization)	
	75-m²	150-m²	13 75-m² rafts	7 150-m² rafts
Capital investment				
Fixed assets	6111	8818	47443	45226
Working capital	4075	5750	33475	34150
Total capital	10186	14568	80918	79376
Operating cost/annum				
Fixed costs				
Depreciation	2237	3809	22681	23363
Licence fee	40	75	500	500
Cost of capital at 10% interest	1019	1457	8092	7938
Total	3296	5341	31273	31801
Variable costs				
Staff salaries	4800[a]	4800[a]	38400[b]	38400[b]
Ropes	1350	2700	17550	18900
Maintenance of boats and miscellaneous	500	1000	3000	3000
Fuel and miscellaneous transport	1500	3000	8000	8000
Total	8150	11500	66950	68300
Total operating costs	11446	16841	98223	100101
Annual returns				
Yield (tonnes) at two harvests per year	25.2	50.4	327.6	352.8
Cost of production (S$/tonne)	454	334	300	284
Return per S$ investment at sale price S$350/tonne	0.77	1.05	1.17	1.23

[a]Workers at $400/month.
[b]Manager at $1200/month; supervisor at $800/month; workers at $400/month.

could be increased because it depends on raft configuration, size, and manner of anchoring. In Spain, up to 40–65% of the water space is utilized for farming (Hurlburt and Hurlburt 1974). The remaining water space is required for anchoring and navigation.

For a 0.5-ha farm only an additional boat and other marginal increases in miscellaneous items would be required to support its activities. To operate a 0.5-ha farm a staff strength of five may be required. This assessment is based on experience gained from mussel research studies conducted by the Department. The cost of production is lowered to S$300 and S$284 for farms containing 13 17-m² rafts and 7 150-m² rafts, respectively.

Location of Farm

The location of the farm, i.e., whether it is within a spat ground or away from a spat ground, affects cost of production because farms outside the spat ground would need to transfer spats from spat-collecting areas to the grow-out areas. A farmer operating away from the spat ground would, therefore, have to maintain a smaller farm in the spat ground for spat-collection purposes.

To increase production and thereby lower production cost, a farmer would need to increase his harvest from two to three harvests per year by having three instead of two rope immersions for spat collection per year. For this, two sets of rope instead of one would be required. While the first set of ropes is laden with on-growing mussels suspended at the grow-out ground, a second set of ropes could be immersed in the spat ground for spat collection. When spats have attached to the second set of ropes, the ropes can then be transferred to the grow-out area to be hung alongside those ropes with on-growing mussels. Depending on spatfall frequency, one harvest is possible every 4 months, i.e., three harvests per year. For a 0.5-ha farm away from the spat ground, a farmer would need to maintain another 0.25-ha farm with three 150-m² rafts at the spat-collecting area. Because spat-laden ropes weigh 25–50% less than ropes at harvest, the stocking density on spat-collecting rafts can be 8–10 ropes/m² instead of 4 ropes/m² as practiced on grow-out rafts.

For farms located within the spat-collecting area, the rafts used for grow-out can also be used for collecting spats and the spat-collecting ropes can be hung alongside grow-out ropes if the farmer so wishes. Hence, a 0.5-ha farm would suffice for either two or three harvests per year with one or two sets of rope. There are also savings in labour because the ropes need not be transferred from one area to another.

A comparison of the costs of operating one farm within the spat ground and another away from the spat ground are shown in Table 5. The costs of production for operating a 0.5-ha farm within the spat ground using seven 150-m^2 rafts are S$284 and S$229/t for two harvests per year and three harvests per year, respectively. The same size farm operated away from the spat ground requires another 0.25 ha in the spat ground for spat collecting. Such a 0.75-ha farm would incur a production cost of S$335 and S$262/t for two harvests per year and three harvests per year, respectively. When a 0.75-ha

Table 5. Comparative costs of operating farms within and away from the spat ground based on 1980 prices (S$2.15 = U.S.$1.00).

	Within spat ground				Away from spat ground	
	0.5-ha farm		0.75-ha farm		(0.75-ha farm)	
	2 harvests/ year	3 harvests/ year	2 harvests/ year	3 harvests/ year	2 harvests/ year	3 harvests/ year
Assumptions						
Sets of ropes used (at 600 ropes/set)	1	2	1	2	1	2
Rafts for production (150 m^2/raft)	7[a]	7[a]	10[a]	10[a]	7[b]	7[b]
Rafts for spat collection (150 m^2/raft)	—	—	—	—	3	3
Analysis (figures in S$ unless otherwise stated)						
Capital investment						
Fixed assets	45226	45226	62180	62180	64180	64180
Working capital	34150	44100	38450	52200	37050	46750
Total capital	79376	89326	100630	114380	101230	110930
Operating cost/year						
Fixed costs						
Depreciation	23363	23363	32890	32890	33290	33290
Licence fee	500	500	750	750	750	750
Cost of capital 10% interest	7938	8933	10063	11438	10123	11093
Total fixed costs	31801	32796	43703	45078	44163	45133
Variable costs						
Staff salary	38400 (56%)[c]	38400 (44%)[c]	38400 (50%)[c]	38400 (37%)[c]	43200 (58%)[c]	43200 (46%)[c]
Ropes (4-m polycoco)	18900	37800	27000	54000	18900	37800
Maintenance of boats and miscellaneous	3000	3500	3500	3500	3500	3500
Fuel and other miscellaneous transport	8000	8500	8000	8500	8500	9000
Total variable costs	68300	88200	76900	104400	74100	93500
Total operating costs	100101	120996	120603	149478	118263	138633
Annual returns						
Yield (tonnes)[d]	352.8	529.2	504.0	756.0	352.8	529.2
Cost of production (S$/tonne)	284	229	239	198	335	262
Return per S$ investment at sale price S$350/tonne	1.23	1.53	1.46	1.77	1.04	1.34

[a]Rafts used for both spat collection and grow-out.
[b]Seven rafts in grow-out area, three located in spat ground.
[c]Denotes percentage of staff salary to variable costs.
[d]Based on 42 kg/4-m polycoco rope per harvest.

Table 6. Cost-benefit analysis of various raft culture operations using 4-m polycoco ropes (based on cost of production calculated in Tables 3-5).

		Within spat ground					Away from spat ground	
		0.5-ha farm			0.75-ha farm		0.75-ha farm	
	Single unit	2 harvests/year		3 harvests/year	2 harvests/year	3 harvests/year	2 harvests/year	3 harvests/year
	2 harvests/year 150-m^2 rafts	13 × 75-m^2 rafts	7 × 150-m^2 rafts	7 × 150-m^2 rafts	10 × 150-m^2 rafts	10 × 150-m^2 rafts	10 × 150-m^2 rafts	10 × 150-m^2 rafts
(1) Cost of production (S$/tonne)	334	300	284	229	239	198	335	262
(2) Total operating cost (S$)	16841	98223	100101	120996	120603	149478	118263	138633
(3) Annual production (tonnes)	50.4	327.6	352.8	529.2	504.0	756.0	352.8	529.2
(4) Gross annual receipts (S$) at S$350/tonne	17640	114660	123480	165220	176400	264600	123480	185220
(5) Return per S$ investment (3 ÷ 2) (S$)	1.05	1.17	1.23	1.53	1.46	1.77	1.04	1.34
(6) Depreciation value (S$)	3809	22681	23363	23363	32890	32890	33290	33290
(7) Total operating cost less depreciation (2 - 6) (S$)	13032	75542	76738	97633	87713	116588	84973	105343
(8) Cash flow before tax (4 - 7) (S$)	4608	39118	46742	87587	88687	148012	38507	79877
(9) Taxable profit (4 - 2) (S$)	799	16437	23379	64224	55797	115122	5217	46587
(10) Tax at 40% of (9) (S$)	320	6575	9352	25690	22319	46049	2087	18635
(11) Net cash return (8 - 10) (S$)	4288	32543	37390	61897	66368	101963	36420	61242
(12) Total capital (S$)	14568	80918	79376	89326	100630	114380	101230	110930
(13) Payout period (2 ÷ 11) (years)	3.40	2.49	2.12	1.44	1.52	1.12	2.78	1.81
(14) Capital recovery factor (11 ÷ 12)	0.2943	0.4022	0.4710	0.6929	0.6595	0.8914	0.3598	0.5521
(15) Internal rate of return for 5 years (%)	14.4	28.9	37.5	>40.0	>40.0	>40.0	23.4	>40.0
(16) Total work force[a] (no. of people/year)	1	5	5	5	5	5	6	6
(17) Productivity (3 ÷ 16) (tonnes/man-year)	50.4	65.5	70.6	105.8	100.8	151.2	58.8	88.2

[a]Includes manager, supervisor, and workers.

farm is entirely operated within the spat ground, the costs of production are S$239 and S$198/t for two harvests per year and three harvests per year, respectively.

Cost–Benefit Analysis

In 1980, the exfarm (farmgate) price of shell-on mussels in Singapore was about S$350/t. Culture operations whose production costs exceed this cost would, therefore, be uneconomical. A cost–benefit analysis of operations whose production costs are lower than the exfarm price is shown in Table 6. Pay-out periods range from 1.12 for a 0.75-ha farm located within the spat grounds, comprising 10 150-m² rafts and operated on a three harvest per year cycle, to 3.40 for a 750-m² farm located within the spat grounds, comprising one 150-m² raft and operated on a two harvest per year cycle. Corresponding capital recovery factors (CRFs) are 0.8914–0.2943, respectively, with internal rates of return (for a 5-year period) varying from >40.0% in the former instance to 14.4% in the latter.

Discussion

Clifton (1980) observed for mussel growing in the United States that small-scale operations are unworkable in a high-wage country and supported Korringa (1976), in his assessment of the Dutch mussel industry, that better profits could be realized through large-scale operations and a high degree of mechanization. The same holds true for Singapore. Staff emolument is the single most expensive item under variable cost, ranging from 37 to 58% (Table 5). This is typical of cultures where the cultured animal and food are derived from the wild and are obtained, more or less, without cost. In cultures where the cultured animal and food are purchased the costs of such items predominate. For mussel culture, where the produce is inexpensive, a high turnover or yield is necessary to justify the high capital outlay on rafts and large-scale operations, because of economies of scale, are therefore more economical to operate than small-scale ones.

The productivity of the work force ranged from 50.4 to 151.2 t/man-year (Table 6). In the United States productivity is calculated to be 33.3 based on 1333 bushels/man-year at 25 kg/bushel, and 150.0 in the Netherlands based on 6000 bushels/man-year (Clifton 1980). In the Philippines, productivity is 24.5 t/man-year, based on 114 man-days or 0.31 man-years for a yield of 7.6 t of mussels at approximately 3.5 kg/gallon of mussels, 6 pesos/gallon, and gross receipts of 12 975 pesos per 0.5-ha farm (PCARR 1977). The high productivity in the Netherlands is attained through a high degree of mechanization. With labour cost on the increase in Singapore, labour-intensive operations like post-harvest handling would have to be similarly mechanized.

Sensitivity tests on the cost of production under varying costs of raft, labour, and yields were conducted (Table 7 gives the results for a 0.5-ha farm within the spat ground). Increases in labour costs were found to have greater impact on production cost than decreases in raft cost. Cost could be reduced dramatically through increases in yields. With larger parent populations established through increased farming activity heavier spatfalls could be expected and

Table 7. Sensitivity test on cost of production (S$/t) for a 0.5-ha farm comprising seven 150-m² rafts located within spat grounds.

	Yield (kg/rope)[a]						Yield (kg/rope)[b]					
	20	42	56	60	70	80	20	42	56	60	70	80
Reduction in raft cost (%)												
0	596	284	213	199	170	149	480	229	171	160	137	120
20	565	269	202	188	162	141	460	219	164	153	131	115
40	535	255	191	178	153	134	440	209	157	147	126	110
60	505	240	180	168	144	126	419	200	150	140	120	105
Increase in labour cost (%)												
0	596	284	213	199	170	149	480	229	171	160	137	120
10	620	295	221	207	177	155	496	236	177	165	142	124
15	632	301	226	211	181	158	504	240	180	168	144	126
20	644	307	230	215	184	161	512	244	183	171	146	128

[a]Two harvests per year.
[b]Three harvest per year.
Note: Dotted line indicates S$350/t sale-price level.

yields would therefore increase. Conversely with overfishing, the parent population would become depleted and poor spatfall would result.

Conclusion

Raft cultures involving nonthinning and using 4-m polycoco ropes on a single 150-m^2 raft and on either 0.5- or 0.75-ha farms were found to be economically feasible in Singapore. Labour cost is the single most expensive item of the variable costs and sensitivity tests show that increases in labour cost would have greater impact on production cost than decreases in raft costs. Increases in yield dramatically reduce the cost of production.

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Discussion

Two major components of expenditures in mussel culture are the cost of the raft and labour. Labour cost in Singapore is relatively high and, hence, mechanization of harvesting and some postharvest operations is recommended. The rafts described in the paper were used for experimental purposes, thus, commercial rafts might be cheaper. Therefore, a reduction in raft cost was considered in the sensitivity analysis study.

The extent of present production must be examined in light of the demand for mussels. This study assumed a constant market price for the product. It is important to study the market for mussels. Fresh mussels may have a limited market but the development of markets — both locally and internationally — for processed mussels might increase the value of the product.

Economic Analysis of Integrated Pig-Fish Farming Operations in the Philippines

Ruben C. Sevilleja[1]

The feasibility of integrating fish with backyard and commercial pig operations is analyzed based on fish yields from experimental pig-fish trials. The main thrust of the experiments was the development of appropriate technologies involving the utilization of pig manure in tilapia production. Although analysis of the experimental integrated project showed that it is operating at a loss, these results do not reflect the true economic potential of the system, because as an experimental project it was not designed to maximize profits. Using partial budgeting techniques, it is estimated that integrated fish production would increase the incomes of both backyard and commercial pig operations. However, the additional capital requirements reduce the rates of return on total investment. It appears that the larger operations will benefit more from integration than the smaller enterprises.

The integration of livestock and fish farming systems has generated interest among farmers for several reasons. Foremost among these is the efficient utilization of resources and the maximization of benefits derived from the farm. Substantial information on integrated livestock-fish farming systems has been reported (Pastakia 1978; Pullin and Shehadeh 1980; Tetangco 1980). In Southeast Asia, the systems in operation have been traditionally carried out at a subsistence level with very limited application of scientific principles. However, the adoption of modern technologies and management procedures is increasing as research data and information become more available. Notable research on the subject has been performed by Schroeder and Hepher (1979), Woynarovich (1979, 1980), Cruz and Shehadeh (1980), and Schroeder (1980).

In the Philippines, information on integrated systems is scarce because the integration of agriculture and aquaculture farming systems is just beginning (de la Cruz 1980). It was only recently that research was initiated as a result of the recognition of the importance of aquaculture to the nation's economy.

As technologies for integrated systems are developed, their economic viability must be demonstrated to justify their adoption and application. However, detailed economic information is limited. Some examples were presented in a review made by Delmendo (1980). Lee (1980) also attempted to compare the economic efficiency of different crop–livestock–fish farming operations in Taiwan. Optimum manure loading rates and corresponding economic returns for Philippine pig-fish operations have been computed by Hopkins et al. (in press).

At this stage of aquaculture research and development, economic problems have become the major area of concern. Areas such as optimum resource allocation, efficiency of investment, operating costs, and incomes have not been clearly established. The economics of integrated fish farming systems warrant further studies to provide government and private planners with useful guidelines for future implementation. This paper aims to partly satisfy this end by presenting an economic analysis of selected integrated pig-fish farming operations.

Case Studies

Three case studies are presented: a commercial growing operation represented by the integrated pig-fish experimental project being jointly undertaken by the Freshwater Aquaculture Center (FAC) at the Central Luzon State University (CLSU) and the International Center for Living Aquatic Resources Management (ICLARM), the CLSU-FAC/ICLARM project; a backyard pig operation; and a small commercial pig breeding and growing operation. The objectives

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of the case studies were to examine the economics of the systems and to determine the feasibility of integrating pig operations with fish production.

Data from the piggery operation of the CLSU-FAC/ICLARM project were analyzed and are presented in the first case study. Eight farmers were visited and interviewed to obtain information on backyard pig operations. The respondents were from within a 15-km radius of CLSU. Because of the difficulty of getting voluntary information from commercial pig breeding and growing operations, basic data from the work of Saturno (1980) were used and the costs and values were updated to 1980 levels. The fish culture sections of all the case studies were based on Hopkins et al. (in press).

Case Study 1: Commercial Growing Operation

This case study is somewhat hypothetical in that the CLSU-FAC/ICLARM project on which this study was based was not designed in a manner appropriate for a commercial growing operation. The project is a 3-ha research facility that has as its principal objective the development of viable animal-fish systems suited to the tropics by the use of replicated experiments. Data from the project were used to design and analyze an 80-head commercial growing operation. Only the size of the ponds (1 ha versus 0.1 ha in the experimental facility) was changed.

Facilities

Pig pens made of concrete and galvanized iron roofing and provided with adequate feeding and drinking facilities were constructed on top of the fishpond dikes. Each pen was connected to the pond by a short channel. Manure or waste matter was conveyed directly into the pond through the channel.

Production Management System

This study is based on Cruz and Shehadeh (1980) and Hopkins et al. (in press). Experiments were run for 180-day cycles (6 months), which correspond to the pig rearing period from weanlings (10–15 kg) to market-size pigs (80–100 kg). The weanlings (Large White - Landrace cross) were purchased from commercial breeding farms and grown according to recommended Philippine practices (PCARR 1976). Daily feeding with commercial feeds was done at the rate of 3–5% body weight. Starter ration was fed until the pigs reached an average individual weight of 20–25 kg, then a grower ration was given until each animal weighed about 55–60 kg. A finisher ration was then fed until marketing.

For each pig growing period, there were two 90-day fish culture cycles. Fish were stocked as fingerlings that weighed 1–10 g. Tilapia (*Sarotherodon niloticus*), which comprised 85% of the total number of fish stocked, was the main species cultured. Common carp (*Cyprinus carpio*) made up 14% and the remainder was composed of *Ophicephalus striatus* (the snakehead or "dalag"), which was stocked as a predator fish. All fish were harvested at the end of each culture cycle by draining the ponds.

Daily manure loading was done simultaneously with pig pen cleaning by washing the pig wastes from the pen directly into the pond. Production functions (Table 1) relating manure input to fish yields were developed by Hopkins et

Table 1. Production functions relating pig manure to yields of tilapia (*Sarotherodon niloticus*) and carp (*Cyprinus carpio*). Based on Hopkins et al. (in press).

For tilapia: $Y = 25.915 + 132.78\ X - 2.655\ X^2$
where Y = net tilapia yield (kg/ha/90 days)
X = fresh manure (t/ha/90 days)

For carp: $\log_e Y = 3.8209 + 0.4736 \log_e M + 0.1771 \log_e B$
where Y = net carp yield (kg/ha/90 days)
M = fresh manure (t/ha/90 days)
B = carp biomass at stocking (kg/ha)

Table 2. Capital costs (P) of three types of integrated pig-fish farming systems, Nueva Ecija, Philippines, 1980 (P7.40 = U.S.$1.00).

	Commercial growing	Backyard	Small breeding and growing
Piggery[a]			
Buildings per pens	53000	2000	80000
Tools and equipment	1000	32	1600
Water system	7000	250	12000
Other fixtures[b]	1000	—	1400
Total	62000	2282	95000
Fishpond[c]			
Pond construction at P10.50/m^3	38360	2756	43071
Water system	2750	1322	2750
Nets at P26/m	2772	975	3120
Buckets at P35 each	3920	350	3850
Total	47802	5403	52791

[a]Based on actual costs updated to 1980 levels.
[b]Includes electrical system, fence, etc.
[c]Based on Hopkins et al. (in press). Assumes an excavated fishpond with gravity water system. Pond sizes are 1.0 ha for the commercial growing operation, 0.12 ha for the backyard operation, and 1.3 ha for the small breeding and growing operation.

al. (in press) and are used here. In using these functions, the manure loading for the first 90-day and second 90-day periods was computed. These values were used separately to compute the appropriate fish yields for each 90-day period.

Total fish production of about 3600 kg/ha/180 days was obtained. The tilapia yield of 3000 kg/ha from the same trial was higher than the average production of 1042 kg/ha/120 days with fertilization and supplemental feeding earlier achieved at the FAC (Guerrero 1976).

Capital Investment

The value of investment items is presented in Table 2. A total of P109 802 (P7.40 = U.S.$1.00) was invested for the facility. About 44% of the total investment was spent for the fish production facility.

Costs and Returns

Table 3 summarizes the costs and returns of the integrated pig-fish experimental facility at the CLSU-FAC/ICLARM project. For analysis purposes, a production cycle of 8 months was considered instead of the actual 6-month experimental trials. The additional 2-month period was necessary for pond preparation, repairs, and maintenance prior to the start of the succeeding experimental/production cycle.

Table 3. Operating costs and returns (P) of three types of integrated pig-fish farming systems, Nueva Ecija, Philippines, 1980 (P7.40 = U.S.$1.00).

	Commercial growing[a]	Backyard[b]	Small breeding and growing
Piggery[c]			
Costs			
Stock/weanlings	27200	1578	12000
Feeds	68551	2405	71899
Labour	3600	—	4896
Drugs and medicine	800	12	2280
Fuel	—	—	1603
Repairs and depreciation[d]	4000	231	6000
Electricity	—	—	3900
Taxes and licences	—	—	11136
Freight	1386	—	—
Total costs	105537	4226	113714
Returns			
Pig sales	88200	5050	116894
Sale of empty feed bags	1188	—	7140
Sale of manure	—	—	2400
Total returns	89388	5050	126434
Net income	(16149)	824	12720
Rate of return on investment (ROI) (% per year)[e]	—	43.2	19.5
Fishpond[f]			
Costs			
Fingerlings at P0.05 each	6000	720	7800
Irrigation fee at P390/ha/year	260	39	338
Land rent at P1950/ha/year	1300	195	1690
Labour at P15/man-day	555	—	675
Manure[g]	—	—	2400
Poison at P10.50/ha/application	21	3	27
Pond maintenance and depreciation	4483	417	3956
Total costs	12619	1374	16886
Returns			
Fish sales:			
Tilapia at P9.00/kg	26820	3735	41436
Carp at P5.00/kg	3000	255	4500
Total returns	29820	3990	45936
Net income	17201	2616	29050
Rate of return on investment (ROI) (% per year)	54	57.6	82.5
Integrated			
Total capital investment	109802	7685	147791
Total costs	118156	5600	130600
Total returns[g]	119208	9040	172370
Net income	1052	3440	41770
Rate of return on investment (ROI) (% per year)	1	54	42

Continued

Table 3 continued

[a]Assumes an 8-month production cycle.
[b]Assumes a 10-month production cycle.
[c]Based on actual costs updated to 1980 levels. Does not include opportunity cost of land used by the piggery because area is minimal.
[d]Estimated.
[e]Backyard: ROI/period × 1.2; other ROI/period × 1.5.
[f]Based on Hopkins et al. (in press).
[g]Opportunity cost of manure (income foregone), for small breeding and growing operation only.

The piggery aspect of the operation incurred losses; however, the income generated from fish production compensated for the piggery operation losses and resulted in a net income of P1052 (Table 3).

Case Study 2: Backyard Pig Operation

This type of pig operation is generally engaged in by operators to augment family incomes.

Normally, it is the housewife and children who do most of the daily animal feeding and pen-clearing activities. Because this type of operation requires minimal attention, the amount of labour spent in the daily routine activities is generally considered by the operators as free (zero opportunity cost).

For this case study, the average number of animals raised was six, although operations with up to 10 head could still be considered as a backyard enterprise (Labadan 1979). Mixed-breed pigs of variable parentage are usually raised. Most of the backyard pig operators indicated rice farming as their main source of livelihood.

Capital Investment

The major investment item for a backyard pig operation was housing (Table 2). It comprised about 88% of the total investment cost. Pig pens varied from the low-cost type made of bamboo with "nipa" or "cogon" as roofing materials, to the more expensive type constructed of concrete hollow blocks with galvanized iron roofs. The former type was common among operators raising up to three head whereas those with more animals in their farm built the more expensive but more durable type. In general, the pig pens had concrete flooring to facilitate cleaning. This in turn allowed for the maintenance of better sanitary conditions.

Production/Management System

Backyard pig operations followed a simple pattern. The operators bought the desired number of animals and raised them to market size at one time. After disposing of the fattened pigs, another batch of animals was purchased and a second production cycle was carried out.

The daily ration of the animals consisted of premixed commercial feeds supplemented with corn grits, broken rice (binlid), or kitchen refuse. Also, the animals were fed daily with fresh leaves of ipil-ipil (*Leucaena leucocephala*), kamote (*Ipomoea batatas*), or kangkong (*Ipomoea reptans*). This system enabled the farmers to gain substantial savings on commercial feeds (BAECON 1976). It took the operators about 8 months to grow their pigs to marketable size.

Costs and Returns

The economics of this system are shown in Table 3. Expenses for the purchase of stock (6 pigs), feeds, and drugs/medicines were the only variable costs incurred by backyard pig operations. Because the operators considered their labour as free, it was not included as a cost item in the analysis. Hence, the computed net income actually represents the residual that accrued to operators for their capital, labour, management, and risk after all expenses were deducted from gross income. The net income from the operation was P824.00, equivalent on an annual basis to about 43% of the total capital investment.

Integration with Fish Production

The feasibility of integrating fish production with existing backyard pig operations was analyzed. The additional capital investment required for the fish production facility was estimated following the guidelines presented by Hopkins et al. (in press). This amount was then reduced to reflect the use of family labour (with zero opportunity cost) in pond construction.

It was estimated that manure production from the backyard pig operations is 153 and 319 kg/pig for the first and second 120-day production periods, respectively. Thus, a fishpond area of about 1200 m^2 is needed with six pigs. This was computed by dividing the amount of pig wastes available (about 2.8 t) by a manure loading rate of 23 t (the equivalent of 53 pigs/ha) multiplied by 10 000. Hopkins et al. (in press) concluded that if manure is limited, ponds with gravity water systems will maximize cash profits when manure is added at the rate of 53 pigs/ha.

Backyard pig raisers needed about 8 months to grow their animals from weanlings to marketable size. Hence, they can have two 120-day fish production periods. To complete the production cycle, an additional 2-month period is needed for pond preparation, repairs, and maintenance.

Using the production functions in Table 1, the fish yields were predicted on the assumption that for a given amount of manure, fish yield will be equivalent for either the 90-day or 120-day production period.

With the integration of fish production, backyard piggery raisers can increase their net incomes by P2616/10 months (Table 3). Computed on an annual basis, this amounts to P3139. With integration, the annual rate of return to operator's capital, labour, management, and risk also increases from 43% to 54%, both higher than the opportunity cost of capital (18–20%).

Case Study 3: Small Pig Breeding and Growing Operation

This study is based on Saturno (1980). The Medina piggery farm is located in Bantug, Muñoz, province of Nueva Ecija in the Philippines. The farm started its operation in 1963 with an initial capital investment of P55 506. The 1980 replacement cost of the facilities was estimated to be P95 000, (Table 2). Of this amount, about 84%

was invested in buildings: farrowing house; sow and litter pens; boar house; growing/finishing pens; and a storage house.

Production/Management System

The farm raises both Large White and Landrace pigs and maintains its own breeders, although animals are purchased occasionally to replace poor breeders. The animals are fed mainly with a farm-mixed ration consisting of rice bran and commercial feed ingredients. The dry lot feeding system is practiced.

At any one time, the farm maintains about 162 animals of various sizes and ages with an approximate total weight of 6680 kg. Fatteners/finishers are raised to the marketable size of 70–90 kg in about 6 months. Culling is practiced to eliminate poor performers.

Costs and Returns

The major expense item for the small pig breeding and growing operation was feeds, which comprised about 63% of the total cost of production. Other major expense items were cost of replacement stock, taxes and licences, and repairs and depreciation. The total cost incurred by the farm amounted to P113 714.

Income from the piggery operation came from the sale of pigs, empty feed bags, and manure. Pig sales as the major income component were from marketed fatteners/finishers, weanlings, and culled animals. The net income generated by the farm was P12 720 or about 19.5% of total capital investment (Table 3).

Integration with Fish Production

The estimated fresh manure available in the farm was 360 kg/day or about 32 t/90 days (5.4% of total pig weight/day). Based on a manure loading rate of 25 t/ha (the equivalent of 80 pigs/ha for the second 90 days) a fishpond area of about 1.3 ha is needed for fish production. This manure loading rate was recommended by Hopkins et al. (in press) to maximize internal rate of return.

As a result of the utilization of pig wastes for fish production the farm sacrifices the income it normally derives from the sale of manure. However, the additional income to be derived from fish sales exceeds the expected additional costs to be incurred resulting from the integration plus income foregone from the sale of manure. An increase in net income of P31 450/8 months may be derived with the integration of fish production to the existing pig operation (Table 3). The annual return on investment increases from 19% for the piggery operation alone to 42% with integration.

Discussion

The promising results obtained from experiments on integrated pig-fish farming have spurred renewed interest among aquaculturists. The utilization of pig wastes as a substitute for inorganic fertilizers and commercial fish feeds is most welcome in view of the rising costs of these farm inputs.

Economic analysis of the CLSU-FAC/ICLARM project indicates that the fish production aspect of the integrated system was profitable. Indeed, in integrated systems, fish production plays a major role, frequently becoming the most profitable part of the enterprise (de la Cruz 1979). The pig production aspect, on the other hand, was not profitable. This was due to the high operating expenses incurred in the pig growing system. Weanlings and feeds were all purchased from commercial sources. Expenses for these items comprised about 91% of the total production costs. Although the beneficial effect of pigs on fish is very evident, the pig production operation should also be profitable. Producing weanlings in the farm and improving feeding efficiency by mixing feeds on the farm may decrease operating expenses and make the system more profitable.

The integration of fish production with existing piggery operations increased the incomes of both backyard and integrated breeding and growing operations within the CLSU area. Backyard pig operators, assuming that they have the capital outlay required to integrate fish production in their farms, increase their gross income by P3999 from the sale of 415 kg of tilapia and 51 kg of carp. This means an additional net income of P2616/0.12-ha fishpond/10 months. The small commercial breeding and growing operators also increase their net income by shifting to an integrated pig–fish farming system.

Conclusions

Several tentative conclusions can be drawn based on this analysis:

- In general, integrated pig–fish farming systems can increase farmers' incomes as the operation maximizes the use of resources. The utilization of pig manure not only increases fish production but also cuts the cost of fish culture operations.
- The CLSU-FAC/ICLARM integrated project is established mainly for experimental purposes. The piggery aspect of the system, however, clearly depicts the problems that commercial

growing operations must face. This type of operation, in which control of weanlings and feed quality is not in the farmer's hand, is not profitable. Purchasing weanlings cuts deeply into the profits.

• Integration of fish production with pig operations increases farm incomes. With integration, the annual rates of return on capital investment of both the backyard and commercial pig operations increased from 43% and 19% to 54% and 42%, respectively.

Recommendations

The ultimate objective of aquaculture research is to develop and generate technologies to accelerate the development of the industry. In most cases, however, investigators are mainly concerned with the quantification and analysis of observed data with very little or no information at all on the economic implications of the results. It may be worthwhile to note the following simple recommendations:

• The majority of production decisions are greatly dependent on economic forces. Whenever possible, production-oriented aquacultural research should include an economic component.

• Biologists in general lack background training in economics. They should seek the assistance of trained economists to analyze the economic implications of their research.

• It is very difficult to compare the economic viability of aquacultural technologies as practiced in different areas or localities. This is because the physical and economic conditions vary from place to place. In this respect, more pilot production testing of various aquacultural technologies should be done for a given locality, scale, and type of operation.

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Discussion

In systems of integrated farming both conflicts and complementarities occur. The objective is to maximize resource utilization. On the one hand, potential risk (e.g., disease) is associated with the system; however, on the other hand, diversification may reduce market risks. There is, therefore, a question of the extent to which integrated farming increases both risks and returns. On balance, integration may be more profitable, but the farmers must always consider the risks involved.

The paper shows that integrated farming is more beneficial to larger-scale operations. Because of the risks involved, large-scale operations necessitate better management. The returns on investment are substantially reduced with integration; therefore, expansion of the hog operation may be more attractive than integration of fish culture. Furthermore, if it is more profitable to sell hog manure in the open market, it should not be used in the integrated farm. The profitability of alternative uses/ disposal of manure need further study.

Except in the partial budgeting analysis, the cost and return analysis did not include land values or any implicit rent. If land rent was subtracted, the return to investment would be lower than computed in the paper.

Pond depreciation is being used by both biologists and economists. If properly maintained, the pond over time will appreciate in value. However, if capital is invested in fishpond development, there is depreciation. Land appreciation could offset depreciation, but it is important to distinguish the two sets of values, particularly because ponds vary in the extent of their development.

Economics of Cage Culture of Tilapia in Sri Lanka

D. C. Galapitage[1]

Cage culture of tilapia is very new in Sri Lanka, and this paper reports on preliminary production trials. An evaluation of the economic feasibility of cage culture in Sri Lanka is conducted and recommendations are made to improve its economic feasibility.

About 60% of the population of Sri Lanka depend solely on fish for their protein requirements. However, per-capita consumption of fish has dropped from 14.3 kg in 1970 to 10.4 kg in 1978. This drop was not due to a reduction in local production, in fact, local production increased from 77 000 t in 1970 to 134 000 t in 1978. Rather, it was caused by a decrease in imports from 45% of local supply in 1970 to 5% in 1978. This reduction in imports was caused by foreign exchange problems in early years and by the unavailability of dried fish in the world market in later years. This example of the ill effects of depending on imports rather than developing local resources has led the Government of Sri Lanka to place more attention on developing local resources to meet the demand for fish.

Of the estimated production of fish in Sri Lanka in 1978, 89% was caught from the sea. Only about 11% was harvested from about 137 600 ha of freshwater tanks. Inland fisheries in Sri Lanka are exclusively reservoir fishing and commercial production is confined to a few major reservoirs. Fisheries in smaller reservoirs operate at a subsistence level.

The development plan for inland fisheries aims at a production of 50 000 t/year by 1983. Such a development strategy involves the utilization of all possible avenues of production in addition to intensification of capture fisheries in the reservoirs. One possible alternative is to raise fish in cages. This paper presents a preliminary study of the technical and economic feasibility of cage culture in Sri Lanka. The first section describes and discusses briefly the organization and results of the first set of trials. The second section looks at the potential profitability of cage culture under varying assumptions of price of feed, feed conversions, and market price of the fish. It also looks at what the required stocking densities would be to just cover all cost in addition to feed. The costs for the cage frame and netting are different than in the first section and are based on known costs for a new experimental design that does not incorporate floating drums and accommodates four 3 × 3 × 3 m cages. In the third section a brief discussion is given on some of the limited baseline data collected on traditional capture fisheries production and marketing. The fourth and final section presents the author's conclusions and recommendations.

Research Project

Because cage culture is entirely new in Sri Lanka, initially three different sites were chosen to represent the major climatic zones:

- Polonnaruwa, which represents the dry zone of the island, receives less than 2000 mm of rainfall (during the Northeast monsoons) and has a temperature range of 24.5–34.5°C,
- Udawalawe, which is also in the dry zone, receives less than 2000 mm of rainfall from the Southwest monsoons and has an annual temperature range of 24–31°C; and
- Nuwara Eliya, which is in the wet zone, represents the cooler area of the country and is usually below 20°C.

The cage culture project began with the installation of 10 box-type cages at each site in February 1980. However, because of poor design and construction, some cages sank and others were destroyed by high waves in the reservoirs. Due to these technical problems, these cages were

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abandoned and new cages were installed in July 1980. These new cages had a bamboo frame and used metal drums for floats. Each unit comprised four cages, and three units, i.e., 12 cages were installed at each experimental site. The overall experiment was designed in the following manner. At each site three feeding trials and two stocking densities were used. At Polonnaruwa, tilapia (*Tilapia nilotica*) were fed either a pellet feed or rice bran or were given no supplemental feed; at Udawalawe, tilapia were given the same feeds; and at Nuwara Eliya, rainbow trout (*Salmo gairdneri*) were given feeds with 30%, 40%, or 50% crude protein.

At all three sites, stocking densities of 600 and 400 fingerlings per cage were used. All experiments were conducted twice. The pellet feed used in the experiments was prepared at the Institute of Fish Technology, Colombo, under the supervision of a feed technologist. The feed for the rainbow trout was prepared on site under the instruction of a feed technologist.

At Nuwara Eliya, rainbow trout were to be used because of the suitable climate and the expected high market price. However, due to the unavailability of a sufficient quantity of fingerlings and other technical and management problems, this experiment could not be completed. It was calculated that meaningful observations were available only at Udawalawe and the following economic calculations are based only on the data obtained from this site.

The main objectives of this economic study were: (1) to develop a suitable approach for the socioeconomic evaluation of a freshwater cage culture system in Sri Lanka; (2) to evaluate the technical and economic feasibility of freshwater cage culture in Sri Lanka; and (3) to recommend further areas of research to improve the potential for freshwater cage culture in Sri Lanka.

Some Advantages of Cage Culture

There are several economic advantages of cage culture that increase the efficiency of resource use. Some of the major advantages are:

- Cage culture, which employs supplemental feeding and the principle of confinement in a water body, can expand fish production above the maximum sustainable yield possible in the natural environment by capture fisheries.
- The efficiency of resource use can be increased by converting a common resource to private ownership. In capture fishery, unless regulation or other controlling methods are introduced, lack of ownership can lead to serious overexploitation and inefficiency in longer-term resource use. However, a system in which fingerlings are stocked and raised in cages may lead to more efficient use of the resources that are employed because of organized and optimized stocking, feeding, and harvesting.
- Cage culture requires less initial capital than starting a pond culture operation. This potentially allows a relatively larger number of people to undertake cage culture.
- Cage culture provides employment opportunities to members of fishermen's families or other local members of the community who are not occupied in capture fisheries. This presents the opportunity for generating additional family income.
- Cage culture can provide fishermen with a more regular income. The income generated from capture fisheries in Sri Lanka's inland water bodies is subject to seasonal fluctuations. Cage culture, with a properly timed production pattern, can provide supplementary income to fishermen during periods of low production from capture fisheries. Cage operators can also take advantage of increased prices during low production periods from capture fisheries to secure good financial returns for their products.
- Consumers benefit because they are assured of a more constant, and increased, supply of fish.

Fixed Costs

In cage culture, fixed costs consist of the capital costs of the cage frame and the net cage.[2] It also includes other materials and the cost of labour used to construct the cages because these are not subject to variation with the changes in production in the short run. Three types of cage frames have been used and their construction costs are shown in Table 1. On a per cage basis, the expenditure on cage frames varies from Rs. 157.00 per harvest for design II using only bamboo to Rs. 361.50 for design III using PVC pipes and empty plastic barrels (Rs. 18.6 = U.S.$1.00). The cost per cage frame per harvest for design I, using bamboo and metal drums, is Rs. 219.25. The costs per square metre are Rs. 24.36, Rs. 17.44, and Rs. 30.13, respectively, for designs I, II, and III.

The total material used in construction contributed the major share to total cost in all cases. Material costs were 88.6%, 79.6%, and 94.5% of total cost for designs I, II, and III, respectively. There are two reasons for the low percentage of

[2]It is assumed that a boat would not be required as an additional investment as fishermen at these sites already own a boat and that freshwater cage culture in Sri Lanka is viewed as a complement not a substitute for traditional freshwater capture fisheries.

Table 1. Capital (fixed) costs (Rs.) of different frame and net types (Rs.18.6 = U.S.$1.00).

	Total cost	Cost/harvest	Percentage of cost/harvest
Frame design I			
(Bamboo frames that accommodate four 3 × 3 × 3 m net cages)			
Material			
Bamboo at Rs. 20/piece	240	120	13.7
Empty metal drums (45-gal) at Rs. 125 each	1125	281	32.0
Paint at Rs. 20 L	80	80	9.1
Rope[a]	532	296	33.7
Labour at Rs. 4/hour	100	100	11.4
Total cost	2077	877	100
Cost/cage	—	219.25	—
Cost/m^2	—	24.36	—
Frame design II			
(Bamboo frames that accommodate two 3 × 3 × 3 m net cages)			
Material			
Bamboo at Rs. 20/L	260	130	41.4
Rope[b]	220	120	38.2
Labour at Rs. 4/hour	64	64	20.4
Total cost	544	314	100
Cost/cage	—	157	—
Cost/m^2	—	17.44	—
Frame design III			
(PVC frames that accommodate two 3 × 4 × 2.5 m net cages)			
Material			
PVC pipes, joints, glue[c]	1554	414	57.3
Empty plastic barrels at Rs. 90 each	540	135	18.7
Rope[d]	268	134	18.5
Labour at Rs. 4/hour	40	40	5.5
Total cost	2402	723	100
Cost/cage	—	361.50	—
Cost/m^2	—	30.13	—
Net cage type I			
(Net 3 × 3 × 3 m)			
Material			
Nylon net (54 m^2 at Rs. 4/m^2)	216	108	71.5
Twine/rope[e]	54	27	17.9
Labour at Rs. 4/hour	32	16	10.6
Total cost	302	157	100
Cost/m^3[f]	—	6.71	—
Net cage type II			
(Net 4 × 3 × 2.5 m)			
Material			
Nylon net (59 m^2 at Rs. 4/m^2)	236	118	69.8
Twine/rope[e]	54	27	16.0
Labour at Rs. 4/hour	48	24	14.2
Total cost	338	169	100
Cost/m^3	—	5.63	—

[a]400 m 3-mm kuralon rope at Rs. 68/100 m and 50 m 10-mm kuralon rope at Rs. 4/m.
[b]10 lb coir rope at Rs. 2/lb and 50 m 10-mm kuralon rope at Rs. 4/m.
[c]40 m 1.5 inch PVC pipe at Rs. 31/m, 4 L-joints at Rs. 22, 8 T-joints at Rs. 24, and 200 g glue at Rs. 17/100 g.
[d]100 m 3-mm kuralon rope at Rs. 68/100 m and 50 m 10-mm kuralon rope at Rs. 4/m.
[e]0.5 lb 12-ply kuralon twine at Rs. 40/lb and 50 m 3-mm kuralon rope at Rs. 68/100 m.
[f]Only 2.5 m of height under water.

labour costs in design III. One was the high cost of material used and the other was the relatively lower labour requirement for constructing the PVC frame.

Designs I and III were constructed for research work and, therefore, were made extremely strong, which added to their cost. Design II was constructed to test the floating capacity of a very simple form that might be used in future commercial operations and it was expected to be cheaper. However, on a per harvest basis, its cost was not as low as expected. In practice, they were more expensive to maintain because the knots had to be thoroughly checked and some of the ropes had to be replaced with fresh coir. In addition to high maintenance expenses, they were unable to withstand high wave action. This type of cage frame must be limited to use in small reservoirs and not used in large tanks where wave action is very high. Its advantage is its relatively low requirement for initial capital.

Two types of net cages were used (Table 1). The cost per square metre and cubic metre for the 3 × 3 × 3 m nets are Rs. 16.78 and Rs. 6.17, respectively. Larger nets, i.e., 30 m^3, would cost Rs. 14.08/m^2 and Rs. 5.63/m^3, respectively. This demonstrates some economy of scale for netting.

Variable Costs

In cage culture, variable costs consist mainly of feed and labour. In Sri Lanka, fingerlings are provided free from government hatcheries and, therefore, in this analysis (done from the point of view of the individual operator) no cost is listed for them.

Cost–benefit analyses were conducted for various combinations of cage frames I and II, net cage type I, two stocking densities, and three feed types. Cage frame design III and net cage type II were not used in the economic analysis because sufficient biological experiments had not been carried out for the larger cages.

A breakdown of the total costs indicated that the capital component is very high and that the variable costs are low in the nonfeeding cases. This is because of the lower expenditure on feed and labour. The reverse is true when feeding is involved. In fact, in some of the feeding cases, the cost of feed and labour contributed up to 65% of the total cost. The cost of labour per cage was estimated by assuming a large cage culture operation where a person can be employed on a full-time basis. The present wage rate paid to a semiskilled person was used in the estimates. Maintenance was estimated as 10% of the capital expenditure per harvest period and included minor equipment used to clean the nets and other minor replacements in the cages.

Interest

A high rate of interest (20%) was taken as the opportunity cost of investment. Bank loans are supplied to the agricultural and fisheries sectors by state banks at a much lower rate (about 15% per year); however, the banks pay 20% per year on fixed deposits. So, if people invest their own funds in cage culture their implicit opportunity cost is not the bank rate at which they can borrow money but the rate at which they could invest their money in a fixed deposit.

Revenue

The revenue components of the analyses were estimated by using the output and market price. The output at the end of 10 months was estimated by extrapolation in all cases except at a stocking rate of 600 fingerlings per cage. This was done to bring all the results into comparable uniform time periods because the other cages were stocked at different times. The extrapolation assumed a linear growth during the entire period.

Revenue was estimated using a price of Rs. 3.30/kg. This price was used on the basis of an initial survey conducted on freshwater fish marketing in Polonnaruwa and Udawalawe. One interesting observation is that the price of freshwater fish at these sites is the same for most of the popular species of fish. Some unpopular species are sold at lower prices, but the catch of these species is less than 5% of the total catch.

There were significant differences in output between feeding with pellet feeds and no supplementary feeding for a given stocking density. In the nonfeeding case, the average size of fish after 10 months was 94 g; whereas, with feeding the fish averaged 142 g, at a stocking density of 600 fingerlings per cage. However, even this growth of the fish after 10 months was insufficient because the fish were well below the size preferred by consumers, which is 250 g or more.

Stocking at 400 fingerlings per cage produced lower yields than 600 fingerlings per cage with and without feeding. This may be the result of poor management of the experiment. The average weight of fish after 10 months was 62 g and 135 g for nonfeeding and feeding, respectively, at a stocking rate of 400 fingerlings per cage. This again indicates that there is a significant difference between feeding and nonfeeding. However, the difference in growth with feedings was not significantly different between the two stocking densities. There is a significant difference in the nonfeeding case. Total fish production at 400 fingerlings per cage was 22 kg and 49 kg without and with feeding, respectively, compared with 51 kg and 77 kg, respectively, at 600 fingerlings per cage. This indicates that by increasing the stocking density from 400 to 600 total output could be increased without incurring serious mortality.

The revenue obtained from cage operations varied from Rs. 72.60 with no feeding to Rs. 254.10 for fish fed pellet feed. The total feed costs at the 400 and 600 stocking densities were Rs. 122.40 and Rs. 530.75, respectively, indicating that these operations failed to recover even their feed costs.

Discussion

The economic analysis done on the basis of this preliminary experimental data indicates that cage culture in freshwater bodies in Sri Lanka is not a profitable method of fish culture. However, the results of the experiments carried out so far should not be taken as final and conclusive. The number of experiments was insufficient due largely to a serious lack of fry and fingerlings. In addition, some unforeseen problems were encountered with respect to extremely bad weather and poaching at some of the sites. However, the experiments were useful in formulating a research methodology to examine cage culture.

A major factor contributing to the losses experienced in these operations was low output of fish. The stocking densities ranged from 300 to 600 fingerlings per 22.5 m^3 cage, or 13 to 27 fingerlings/m^3. This density is far below the stocking rates of 250–1000 fingerlings/m^3 practiced in other countries for *T. nilotica*. The second reason for the unprofitability was the unfavourable price situation for fish. With the feed conversion ratios experienced in the cages at stocking densities of 400 and 600 fingerlings per cage, the feed costs alone were Rs. 6.44/kg and Rs. 6.88/kg of fish produced using pellet feed and rice bran, respectively. Because a kilogram of fish could be sold for only Rs. 3.30, it was not possible to cover even feed costs.

Calculations of Potential Cage Culture Profitability

Given the results of the initial trials discussed in the first section, it was decided that for the remainder of the project, further trials would be limited to one site (Udawalawe), where sufficient fingerlings were available for various experiments utilizing a total of over 20 cages. These trials are now under way; therefore, some of the data provided in this section of the paper regarding costs of the cage (frame, netting, and labour), size of cage, composition and costs of feed, and stocking density are known and related to those in the new trials. However, assumptions are made with respect to feed conversion rate, mortality, harvesting size of fish, price of fish, variable labour, interest, and expected life of the cage. The following analyses focus on changes in the assumed values for cost of feed, feed conversion, and life of the cage and look at the effect on the required stocking density and break-even price for fish.

The following parameters are constant in both cases discussed below: size of cage (27 m^3); harvested size of fish (250 g); variable cost of labour (Rs. 300); mortality (10%); interest on capital (20%); and fingerlings/fry (free of charge).

Case No. 1

In this case, cost of cage is Rs. 1275; cost of feed is Rs. 2.21/kg (present cost of commercial pellet feed in Sri Lanka); feed conversion is 2.5:1; life of cage is one season (8 months); stocking density is 200 fingerlings/m^3 (present stocking density at Udawalawe trial); and price of fish/kg is Rs. 3.30 (present wholesale or fisherman's price at Udawalawe). Therefore, for each 27 m^3 cage: fixed costs (Rs.) would be the cost of the cage (1275) plus interest (255) or Rs. 1530; variable costs (Rs.) would be labour (300) plus feed (7456) or Rs. 7756; total costs would be Rs. 9286; revenue would be Rs. 4010 (1215 kg × 3.3); the loss would amount to Rs. 5276.

Even before going through these simple calculations, one could see from the data given that the feed costs alone per kilogram of fish exceeded the price of a kilogram of fish by Rs. 2.23. Therefore, as long as the marginal feed cost per kilogram of fish exceeds its market value, reducing the costs of a cage per growing season or increasing the stocking density will have no effect on making the system profitable given these parameters for feed costs, feed conversion, and market price of fish. Actually, increasing the stocking density would only compound the total loss through a higher production of uneconomically produced fish.

The following calculations show: (1) what the cost of feed would have to be reduced to in order to break even at a market price of fish of Rs. 3.30/kg; and (2) what the price per kilogram of fish would have to be increased to in order to cover all costs if the cost of feed remained unchanged.

To cover variable feed costs alone, we know that a kilogram of fish must equal Rs. 5.5, but, in addition, all other variable and fixed costs must be covered. From the above we see that the total costs of producing 1215 kg of fish are Rs. 9286 or Rs. 7.64/kg. Therefore, the market price would need to increase by 132%. This is extremely unlikely for tilapia in Sri Lanka in the foreseeable future.

From our example we also know that total revenue equals Rs. 4010 and all nonfeed costs equal Rs. 1830. Therefore, to break even only Rs. 2180 could be used for feed to produce 1215 kg of fish. This means a feed cost of Rs. 1.79/kg of fish produced. If the feed conversion ratio (2.5:1) remains unchanged, then the price of feed would have to be reduced from Rs. 2.21/kg to Rs. 0.72/kg, a decrease of 67%. It is highly unlikely that a feed costing 67% less would be able to give the same, or a similar, feed conversion ratio.

From this example, we can see that a significant positive difference between the market value of a kilogram of fish and the feed costs per kilogram of fish produced, and stocking densities are as high as possible without incurring significant disease and/or mortality, are required to provide reasonable economic feasibility to cage culture production of tilapia in Sri Lanka.

Case No. 2

The following example assumes a situation in which the cost of feed is Rs. 0.70/kg, the feed conversion ratio is 3.5:1, the market wholesale price of fish is Rs. 4/kg, and the life of the cage is expected to be three seasons (not an unusual expectation for placement in fresh water). In such a situation, the cost of the cage (per season) is Rs. 425; interest (per season) is Rs. 85; labour is Rs. 300; the cost of feed per kilogram of fish is Rs. 2.45; the difference between market price and feed cost per kilogram of fish is Rs. 1.55; the harvested weight of fish is 250 g; and the total costs excluding feed are Rs. 810.

Therefore, given this difference of Rs. 1.55 between the price of a kilogram of fish and feed cost per kilogram, it would require that to break even a single cage produce 523 kg of fish ($810 \div 1.55$). This would be equal to 2301 fish ($523 \div 0.250 = 2092$ plus 10% for mortality) per cage or a stocking density of $2301 \div 27 = 85/m^3$. This is an extremely low stocking density. If we assumed a stocking density of $200/m^3$ as in the present Udawalawe trials then the profit realized in this example would be Rs. 894 per cage (if the break-even stocking density is 85 m^3, then with the new stocking density of $200/m^3$; 115 fry $\times$ 27 m^3 would have a marginal feed cost of Rs. 1902, give an additional production of 699 kg of fish allowing for 10% mortality, and a marginal revenue of Rs. 2796).

Higher stocking densities should be technically feasible, at least up to $500/m^3$ or more when supplementary feeding is given. However, while the results of this example are certainly much more encouraging than in Case No. 1, it is still only an example that underlines the need for further research on lower cost feeds, higher stocking densities, and possibly other species that require less supplementary feeding and/or have a higher market value than tilapia and further trials in sites with higher natural water productivity.

Characteristics of Traditional Freshwater Capture Fisheries

Table 2 presents information on total production, number of craft, number of fishermen, and income per fisherman on a monthly basis in capture fishery at Parakrama Samudraya, Polonnaruwa. The average catch per fisherman per month is 520 kg. After deducting one-third of income for the craft and fishing gear the average income per fisherman per month is Rs. 1144.00 at Rs. 3.30/kg of fish. This income is subject to large fluctuations due to seasonal variation in production. Income varies from Rs. 380.00 in June to Rs. 2485.00 in October.

Usually a fishing craft is operated by two fishermen. The income is divided into three and one part is allocated for the craft and fishing gear. The total allocation of income per craft in 1980 was Rs. 14 142.00. The average cost of a craft and a set of fishing gear, whose lifetime is estimated to be one and one-half years, is about Rs. 6000.00. On a depreciated basis the annual capital cost is Rs. 4000.00. This leads to a net annual return to capital of $(14\,142 - 4000)/4000 \times 100 = 253.55\%$. In addition, the annual return to labour is on average equal to Rs. 13 776.

The fish caught in traditional freshwater capture fisheries are sold to "cycle" vendors who take the fish to the towns, fairs, and colonies (villages) for sale to consumers. Usually a fisherman sells his catch to a particular vendor. The catch is sold to another vendor only if the regular vendor is not present. This is particularly true during periods of low production. In the high production period the vendor maintains this

Table 2. Information on capture fisheries at Parakrama Samudraya, Polonnaruwa.[a]

	No. of craft	No. of fishermen	Production (kg) Total	Production (kg) Per man/month	Value of monthly output (at Rs. 3.30/kg)[b]	Share of income to craft and gear/month/craft	Income/man/month
Jan	80	148	83312	563	274930	1146	1238
Feb	79	186	76200	410	251526	1061	902
Mar	79	185	99568	538	328574	1386	1184
Apr	82	190	76200	401	251460	1022	882
May	85	195	72136	370	238049	934	814
June	85	188	32512	173	107290	421	380
July	88	200	122936	615	405689	1537	1352
Aug	93	215	64008	298	211226	757	655
Sept	103	206	50800	247	167640	543	543
Oct	105	206	232664	1129	767791	2437	2485
Nov	105	206	186944	907	616915	1958	1996
Dec	105	206	122936	597	405689	1288	1313
Total	—	—	1220216	6248	4026779	14490	13744
Average	—	—	101685	523	335565	1207.50	1148

[a]Computed from the data obtained from statistics branch, Ministry of Fisheries, Colombo, for the year 1980.
[b]Rs. 18.6 = U.S.$1.00.

relationship by buying only from the fisherman who sold fish to him during the low production period. Fish are bought from other fishermen only if the usual fisherman is not present or his catch is inadequate.

The vendors as a group are better organized than the fishermen. The nature of the activities of each group also keeps the vendors in a strong position. Because of the highly perishable nature of fish, fishermen have to dispose of their catch as soon as possible. The alternatives available are either to sell them to other fishermen or to dry them. After the tiring work of catching the fish they prefer to sell them fresh rather than for processing and drying. During the rainy season, when the catch is very high, sun drying is very difficult, and because of a shortage of firewood, smoking on a large scale is also not possible. These factors affect the bargaining power of fishermen.

Vendors, on the other hand, are in a position to refuse to buy the fish if the fishermen do not agree to the vendor's terms. This is because the vendors are not solely dependent on selling fish for their livelihood and have alternative employment. The fishermen do not seem to have this alternative. Under this situation, the fish price is kept at a low level by the vendors.

Several attempts have been made by Ministry of Fisheries appointed fisheries inspectors to encourage an increase in the price during the low production period. These efforts have failed because of the situation explained above. However, with inflation of the prices of other consumer goods, the vendors, in recent times, have agreed with the fisheries inspectors on the need for limited increases in the price of fish. An additional reason the vendors are unwilling to pay a higher price is that they are unable to sell fish at a higher price to consumers. This is mainly because freshwater fish are not well liked in Sri Lanka; the majority of the population considers them to be inferior to marine fish.

Conclusions and Recommendations

The technology of raising fish in cages requires further development to adapt it to the biological and socioeconomic environment in Sri Lanka. Further research should be carried out using locally available cheap feed. However, care should be taken not to drastically alter the feed conversion ratio. If the conversion ratio is seriously affected by using cheap feed, the unit feed cost will be reduced but the period of production may be increased and result in increased expenditures on total feed and labour and on the total cost per kilogram of fish. To recover other variable costs and fixed costs and to guarantee a competitive return on investment, cost per unit of fish should be reduced. For this purpose, further experiments should also be carried out with increased stocking densities and improved feeding practices.

Research should be focused on using other species of fish, especially to reduce the feed cost component. Species like bighead carp, which are mainly plankton feeders may be suitable. This research should also be carried out in reservoirs rich in natural food. Because a major component of the cost (up to 65%) in cage culture is feed and feeding labour, it is worth investigating the culturing of fish without feeding. Should this be possible, a major breakthrough in fish culture in Sri Lanka will be possible.

Discussion

Because the cost of the feed was more than the value of the fish produced, a very different feed should be used. Reducing variable costs in this manner would be preferable to trying to increase market prices. It was noted that feeding experiments are continuing.

Relative prices of freshwater fish are very low, especially in the cities, when compared with the price of marine species, because consumers prefer the latter. This may make it necessary for the government to subsidize aquaculture in its early stages until consumer preference can be influenced through test marketing of alternative product forms.

Several participants questioned why cage culture was being introduced in Sri Lanka. Claims were made that alternatives to cage culture could have been pursued (e.g., pen culture in brackish water, adapting selected marine species to freshwater, upgrading culture in community reservoirs). In the ensuing discussion, it was pointed out that cage culture should not be discontinued yet because the technical experiments are only just beginning. A small number of entrepreneurs appear to be interested in investing in these new culture methods. But, when the private sector is reluctant to enter a new, possibly high-risk venture, it is appropriate for funding agencies to support experimental projects until production and management techniques are improved. It was generally agreed that technical problems of cage culture in Sri Lanka should take priority at this stage, and that further economic analysis be deferred until new technical and biological data become available from subsequent trials.

An Economic Analysis of Composite Fish Culture in India

S.D. Tripathi[1] *and M. Ranadhir*[2]

Production aspects of composite (polyculture) systems are described. The majority of the farms that were studied reared various species of exotic carps and local Indian varieties and produced yields as high as 6–7 t/ha/year. However, maximizing production will not maximize profits. Feed is identified as the major component of cost, and extensive data on feed input levels and observed output levels are reported. Wide variations in yield occur even for similar feeding levels. Optimum input levels for feed are determined using the total cost/total revenue approach.

Fish culture in India has been traditionally confined to the eastern region, which presently comprises the States of Orissa, West Bengal, Bihar, and Assam, and is deeply rooted in the social milieu. Fish not only forms a component, along with rice, of the staple diet but is an item of great importance in all social and religious functions. Fish culture is practiced in freshwater ponds, either alone or integrated with agriculture (rice paddies) and duck culture, and also in brackish-water impoundments with or without integration with rice. Freshwater fish culture is so advanced that the farmers have selected suitable cultivable species and know their breeding and feeding habits. Elaborate techniques to collect their seed from natural breeding environments such as flooded streams and rivers are known and the species can even be artificially induced to spawn selectively in what are known as dry bunds. The art of hatching and rearing young fish is equally well developed. Natural food, however, forms the mainstay of these culture operations and is maintained/increased by occasional fertilization. Although brackish-water aquaculture is still in its infancy in India, freshwater aquaculture can be said to have come of age.

Traditional Aquaculture Technology

Fish farmers, in general, prepare the ponds early in the monsoon season by an initial application of mustard oilcake and/or mahua (*Bassia latifolia*) oilcake after thorough netting. The quantity of cake used varies from place to place and farmer to farmer. The decomposing cake possibly kills some predatory and weed fishes, but the farmers aim at production of fish food organisms rather than eradication of unwanted fish.

Some farmers stock the spawn itself even in ponds as large as 0.5–1.0 ha, but fry and early fingerlings are generally used for stocking large ponds. The seed is procured from spawn markets or through vendors. The quantity of seed stocked under traditional aquaculture has no scientific basis and depends on the whims of the farmer. Generally, stocking is done at an alarmingly high rate and survival is exceedingly low. Growth is very slow and poor in ponds that are inherently unproductive or have low productivity where further fertilizer (cake) applications are not made or where cow dung, pig dung, or duck excreta are not applied or received inadvertently, and where multiple cropping is not practiced. Fish are often parasitized and grow only to 200–250 g in 1 year, and production does not exceed 300–400 kg/ha. Advanced farmers, however, take far greater care of their stocks and start repetitive thinning from the beginning, which results in better growth of the remaining stock and maintenance of hygienic conditions. These farmers harvest as much as 1000 kg/ha, or even more in certain cases. However, a very large quantity of the seed is generally wasted in traditional farming. Supplementary feeding is unknown in traditional aquaculture in India.

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Composite Fish Culture Technology

Intensive research on optimizing per hectare production from fish ponds was started at the Freshwater Fish Culture Division of the Central Inland Fisheries Research Institute in the mid-60s. Control of trash fish, periodic fertilization, and supplementary feed were incorporated as basic ingredients of the technology. Various combinations of indigenous major carps, exotic carps, and both indigenous and exotic carps were tried and a combination of the three indigenous carps (*Catla catla, Labeo rohita,* and *Cirrhinus mrigala*) with three exotic carps (*Hypophthalmichthys molitrix, Ctenopharyngodon idella,* and *Cyprinus carpio* var. *specularis*) was found to give the best results and was called composite fish culture to distinguish it from the traditional polyculture of indigenous major carps. The new technology was further elaborated, perfected, and tested in various agroclimatic regions of India under an All India Coordinated Research Project on Composite Fish Culture, and production levels as high as 10 300 kg/ha/year were obtained. However, production, in general, ranged from 2500 to 6300 kg/ha and depended greatly on soil quality and the inherent fertility of the ponds.

In brief, the technology involves (1) complete eradication of predatory and weed fishes by application of a vegetable fish toxicant (mahua oilcake at 2500 kg/ha-m); (2) liming at 200–1000 kg/ha depending on soil pH; (3) stocking of fingerlings (100–150 mm) of *C. catla* (10–15%), *L. rohita* (25–30%), *C. mrigala* (15–20%), *H. molitrix* (20–30%), *C. idella* (5–10%), and *C. carpio* (10–20%) at 4000–7500/ha; (4) fortnightly fertilization of ponds with organic manures (cow dung) at 750–1500 kg/ha followed alternately with application of inorganic fertilizers such as ammonium sulfate (450 kg/ha) or urea (200 kg/ha) depending on soil pH, superphosphate (200 kg/ha) and muriate of potash (40 kg/ha); (5) provision of supplementary feed, generally a 1:1 mixture of groundnut/mustard oilcake and rice bran/wheat bran at 1–5% of the total body weight of the fish and provision of aquatic/terrestrial weeds or horticultural wastes (cabbage/cauliflower leaves) for grass carp to satiation; (6) periodic netting, preferably monthly, to assess the growth and health of fish and (7) maintenance of pond hygiene.

With a view to increasing fish production from village ponds and improving the rural economy, the technology of composite fish culture was demonstrated in farmers' ponds during 1975–79 under the CIFRI/IDRC rural aquaculture project. The project covered 41 villages in six districts of West Bengal and 32 villages in five districts of Orissa and fish production of 2000–6000 kg/ha/year was demonstrated under field conditions. Very high production of the order of 7550 kg/ha/10 months with an average production of 6275 kg/ha/10 months was demonstrated in nine ponds at Malda Centre (West Bengal).

Biological Interactions Between Input and Output

Although it is known that inherently productive ponds require less input and yield a higher output, the level of output is always determined by the level of input. Of the various inputs, the density, size, and time of stocking of fingerlings, the quantity of fertilizer used, weeds provided to the grass carp and the supplementary feed given the other fishes determine total output to a great extent.

Stocking Density, Size, and Time

Stocking densities above 4000 fingerlings/ha require higher inputs in terms of fertilizers and feeds but often create biological hazards resulting in mortality and poor growth of fish. However, higher yields are also a function of high stocking densities provided a balance of both natural and supplementary feed is well maintained. A stocking density of 4000 fingerlings per ha can yield a production of 3 t/ha at a low input of feed and fertilizers and normally involves no risk of biological hazards.

The size of the fish and the time they are stocked directly affect production. Although in certain experiments at the Pune Centre (Maharashtra) of the All India Coordinated Research Project on Composite Fish Culture, a production of over 10000 kg/ha/year has been obtained when fry were stocked at 8000/ha, it was the time of stocking, the species composition, and replenishment of water that contributed to high production. When fingerlings are stocked in early July, they grow sufficiently fast until the end of October and take full advantage of high temperatures, large water volume, and abundant natural food. If stocked at smaller sizes, survival rates are very low, especially in the case of grass carp, common carp, and *L. rohita,* and production is directly affected.

Use of Fertilizers

Cow dung and some inorganic fertilizers are now easily available even in remote villages and farmers who have problems purchasing, transporting, and storing fish feed can rely on the use of fertilizers alone to increase fish yields. Experiments have shown that production levels of 2300–2600 kg/ha can be obtained in 8–9 months by using cow dung at 10 000 kg/ha and inorganic fertilizers (urea/ammonium sulfate, superphosphate, and muriate of potash) at 500 kg/ha. This low-cost technology best suits farmers in rural areas.

Experiments are currently in progress on the use of biogas slurry, and there are indications that slurry alone will yield far higher levels of production than both organic and inorganic fertilizers.

Supplementary feed

Supplementary feed is the most expensive input in composite fish culture and involves problems of both cartage and storage. While feed alone yields a sufficiently high production of 4000–5000 kg/ha, it is expensive (Rs. 3.40 of input/kg of fish produced) (Indian Rs. 8.85 = U.S.$1.00). Although large quantities of feed are required, this is a suitable technology for achieving high production where running water is available or facilities exist for replenishing the water in the fish ponds and where the market price of fish is relatively high. Production of 10 210 kg/ha was obtained at Pune when 20 748 kg/ha of feed was used in addition to organic and inorganic fertilizers.

Where the aim is intensive culture for raising large-scale commercial crops of relatively high market value, entrepreneurs would be interested in providing a higher input of feed to achieve their goal of higher outputs. However, yields are also high when ponds are periodically fertilized and supplementary feed is provided regularly. In such combinations, average yields of 6170 kg/ha have been obtained in 8–9 months with an average input cost of Rs. 2.50.kg. This technology is perhaps more appropriate for a larger group of farmers in both near urban and urban areas where the market price of fish is usually higher than in rural areas of the country.

Case Studies

Traditional

Traditional practices are simple and do not involve many operation inputs. The major cost component in traditional operations is seed, which is about 50% of the total cost. Productivity is low and consequently the farm business income is equally very low (Table 1). As a result of low productivity, the cost of production per kilogram of fish is high when compared with other types of fish culture operations and is estimated at about Indian Rs. 6.60/kg.

Because profits are low in traditional fish culture operations, the impact of new aquaculture technology is already being felt in the rural areas as more and more traditional fish farms adopt new aquaculture practices. It is difficult to expect them to adopt all the scientific practices in toto, and, thus, undergo technological change in a short period. Great scope, however, exists in India for adoption of new aquaculture technology because of the high remunerative farm business income demonstrated by scientific and pilot-scale operations and because of the seemingly insatiable market demand. However, there are constraints to the speedy adoption of the new technology by farmers. These constraints relate to procurement of quality fish seed, particularly Chinese carps; easy flow of credit from financial institutions; and extension mechanisms in the hinterland of the country. Once these constraints are removed, it will be possible to enhance inland traditional fish culture production by at least four to five times. The increasing price of freshwater carps during the last 6–8 years indicates the country's supply position in relation to its demand. A positive sign of technological change was observed in the state of West Bengal where a number of fish farmers, who had been operating on traditional lines, switched to the new technology. In these cases, the new technology has increased profits by at least Rs. 15 000/ha of culturable water area,

Table 1. Annual costs and returns (Indian Rs./ha) of a traditional fish culture operation in India (Rs. 8.85 = U.S.$1.00).

Costs	
Pond rental	2000
Pond preparation with mahua/mustard oil cake	1000
Stocking at 75000–100000 fry	3000
Harvesting charges	600
Total cost	6600
Returns	
Yield at 1000 kg/ha	
Gross income at Rs. 9/kg	9000
Gross farm business income	2400
Ratio of business income to gross income	26.6%

which means that the operation is eight times more profitable than traditional operations.

Considering the social aspects of traditional fish culture, the country cannot afford low productivity from its fishponds because of the increasing need to meet the protein requirements of its growing population. This is particularly true when an alternate technology is available that promises 10 000 kg/ha/year of profitable production.

Experimental

It has been demonstrated in India through many experimental fish farms that productivity is 10–14 times higher with the new aquaculture technology than with traditional operations. The major cost component is supplementary feeding, which amounts to as much as Rs. 21 000 or 67% of the total cost incurred in production. Although the total operational costs are considerably higher in experimental fish farms, the profits (125%) are also outstanding. Fish culture operations conducted at experimental fish farms have clearly shown that additional expenditures of Rs. 30 000/ha are worthwhile. Because productivity is high in experimental fish farms, the unit cost of production is relatively low and is estimated at current price levels at Rs. 4.30/kg as against a prevailing farmgate price of about Rs. 9.00/kg (Table 2).

Pilot-Scale Operations

In a large number of cases, the application of composite fish culture technology in farmers' ponds has yielded production levels ranging from 4000 to 6000 kg/ha of culturable water area. The gap between current experimental levels and the levels obtained under field conditions may be due to lower levels of supplementary feeding in the pilot farms. The average profitability of about Rs. 20 000/ha, obtained by private fish farmers in West Bengal in field demonstration trials, is very lucrative compared with other economic activities involving land use. The application of mahua oilcake is useful for fertilizing the pond in addition to its use to eradicate predatory and

Table 2. Inputs, yield, costs, and income of composite fish culture from an experimental fish farm in India (costs approximated to nearest Indian rupee).

Item	Quantity (kg/ha)	Costs (Rs./ha)	
		Initial	Annual
Capital costs			
Land: 1 ha, 20-year payout	—	20000	1000
Construction: 25-year amortization	—	35000	1400
Fish farming equipment: 5-year amortization	—	2500	500
Interest on amortized capital funds at 12%/year	—	—	3500
Subtotal		57500	6400
Operational inputs			
Mahua oilcake at Rs. 0.80/kg	2000	—	1600
Lime at Rs. 0.60/kg	263	—	158
Cow dung at Rs. 50.00/1000 kg	8750	—	438
Urea at Rs. 2.00/kg	137	—	274
Triple superphosphate at Rs. 1.70/kg	117	—	199
Fingerlings at Rs. 150/1000	10000	—	1500
Groundnut oilcake at Rs. 1.80/kg	9213	—	16583
Rice polish at Rs. 0.60/kg	7938	—	4763
Weeds	7812	—	256
Wages at Rs. 8/day	—	—	2880
Miscellaneous costs 5% of operational costs	—	—	1288
Interest on operating capital at 12% half-yearly	—	—	1800
Subtotal			31739
Grand total			38139
Gross yield: 8867 kg/ha			
Gross income at Rs. 9/kg: Rs. 79803			
Gross farm business income/ha: Rs. 41664			
Cost of production: Rs. 4.30/kg			
Ratio of farm business income to total costs: 109%			
Ratio of farm business income to gross income: 52%			

weed fishes. This reduces the use of supplementary feed by about 4000 kg and produces a net saving of about Rs. 3000/ha. The cost of production is aboutRs. 5.00/kg thus assuring the farmer a profit margin of about Rs. 4.00/kg of fish produced (Table 3).

Low-Cost Technology

The total costs involved in the production process can be considerably reduced by complete elimination of supplementary feeding. The gross yield possible with this type of fish culture practice is about 2700–2800 kg/ha. The ratio of profitability to operating costs is 60%. Because production is not high, the cost of production is about Rs. 5.60/kg but even this fetches a profit of about Rs. 9300/ha. The major operational input is mahua oil cake, which is 7% of total costs. Annual capital costs account for 42% of total costs (Table 4). Low-cost technology is worthwhile for poor and marginal fish farmers who are not in a position to invest heavily in the new aquaculture technology.

Farm Business Income

The case studies were analyzed and farm business income and other economic indicators were calculated. Because the data relate to different years, the costing of annual capital costs and operational costs was done at current price levels (1980–81) so that the case studies would be comparable. Capital costs, wages, and interest, not available in the data published on the case studies, have been imputed at current prices to make a complete farm business analysis. With amortization of capital funds and payout costs of land, the annual cost for 1 ha of pond is Rs. 6400 at current price levels. These annual cost estimates are based on new farm construction. But the rental value of existing water bodies ranges from Rs. 2000 to 3000/ha, which appears to be a

Table 3: Inputs, yield, costs, and income of composite fish culture from a farmer's pond at Hanspukur (West Bengal) under CIFRI/IDRC rural aquaculture project during 1976–77 (costs approximated to the nearest Indian rupee).

Item	Quantity (kg/ha)	Costs (Rs./ha)	
		Initial	Annual
Capital costs			
Land: 1 ha, 20-year payout	—	20000	1000
Construction: 25-year amortization	—	35000	1400
Fish farming equipment: 5-year amortization	—	2500	500
Interest on amortized capital funds at 12%/year	—	—	3500
Subtotal		57500	6400
Operational inputs			
Mahua oil cake at Rs. 0.80/kg	6000	—	4800
Lime at Rs. 0.60/kg	360	—	216
Cow dung at Rs. 50.00/1000 kg	1000	—	50
Ammonium sulfate at 1.66/kg	88	—	146
Single superphosphate at 0.84/kg	41	—	34
Fingerlings at Rs. 150/1000	5000	—	750
Groundnut oilcake at Rs. 1.80/kg	2766	—	4979
Rice bran at Rs. 0.60/kg	3212	—	1927
Aquatic and terrestrial weeds	34485	—	1280
Wages at Rs. 8/day	—	—	2880
Miscellaneous costs at 5% of operational costs	—	—	709
Interest on operating capital at 12% half-yearly	—	—	1066
Subtotal			18837
Grand total			25237
Gross yield: 5004 kg/ha			
Gross income at Rs. 9/kg: Rs. 45036			
Gross farm business income/ha: Rs. 19799			
Cost of production: Rs. 5.04/kg			
Ratio of farm business income to total costs: 78%			
Ratio of farm business income to gross income: 44%			

Table 4: Inputs, yield, costs, and income of composite fish culture from a demonstration pond without using supplementary feeding (costs approximated to the nearest Indian rupee).

Item	Quantity (kg/ha)	Costs (Rs./ha) Initial	Annual
Capital costs			
Land: 1 ha, 20-year payout	—	20000	1000
Construction: 25-year amortization	—	35000	1400
Fish farming equipment: 5-year amortization	—	2500	500
Interest on amortized capital funds at 12%/year	—	—	3500
Subtotal		57500	6400
Operational inputs			
Mahua oilcake at Rs. 0.80/kg	1500	—	1200
Lime at Rs. 0.60/kg	300	—	180
Cow dung at Rs. 50.00/1000 kg	7500	—	375
Ammonium sulfate at 1.66/kg	396	—	657
Single superphosphate at 0.84/kg	240	—	202
Muriate of potash at Rs. 1.12/kg	50	—	56
Urea at Rs. 2.00/kg	30	—	60
Weeds	23170	—	768
Fingerlings at Rs. 150/1000	6000	—	900
Other items like diesel oil, mobil oil	—	—	976
Wages at Rs. 8/day	—	—	2880
Miscellaneous costs at 5% of operating costs			269
Interest on operating capital at 12% half-yearly			511
Subtotal			9034
Grand total			15434

Gross yield: 2746 kg/ha
Gross income at Rs. 9/kg: Rs. 24714
Gross farm business income/ha: Rs. 9280
Cost of production: Rs. 5.62/kg
Ratio of farm business income to total costs: 60%
Ratio of farm business income to gross income: 38%

cheaper way of conducting fish culture operations in India and is also the traditional practice. Water bodies are taken on lease because of their easy availability on a large scale. In such cases, the farm business income will be increased by about Rs. 3000/ha.

However, if one wishes to enter the fish-farming business on a large scale, it may be necessary to have the farm complex in one compound. Because such fish farms are rarely seen in the private sector, it would be necessary to construct new farms for large commercial operations. Keeping this in mind, the maximum annual fixed capital costs for commercial fish farm operations are indicated in Tables 2–4 as Rs. 6400/ha. The gross farm business income for experimental fish farms is Rs. 41 664/ha/year. For pilot-scale operations (taking an average case study conducted at Hanspukur under the CIFRI/IDRC rural aquaculture project) a gross farm business income of Rs. 19 799/ha/year has been shown to be possible under existing prices. These high returns make it attractive to initiate new aquaculture ventures or convert traditional ponds to suit the new technology, which offers a pay-back period of 2–3 years. Because profitability is about Rs. 9280/ha for low-cost technology, about 6 years would be required to recover the initial capital investment. However, it may be worthwhile to use existing ponds that can be taken on lease rather than construct new ponds for low-cost technology in rural areas.

Problem Areas for Research

At the microlevel of fish culture operations, it is very important to know the combination of inputs that will produce optimum production. The main problem relating to composite fish culture in India is that it involves six species in a number of possible combinations. Any variation in species combination is likely to affect the yield even if all other inputs are kept constant. It is, therefore, essential that the optimum species combination be known before undertaking any further economic research. Once this optimal combination is known, marginal cost and marginal revenue concepts can be used to maximize farm business income. Maximum farm business income need not necessarily accrue when output is maximized, which means showing eagerness for maximum yield is not always consistent with income maximization. This is one area where further economic research can be undertaken.

Building economic models to determine which variables significantly affect the yield of the production process can be undertaken and dummy variables can be used to account for environmental and soil characteristics. Research on the optimization of the production process has already been initiated at the Freshwater Aquaculture Research and Training Centre, Dhauli. Although the optimization process is mainly an economic tool, it requires a multidisciplinary approach. This multidisciplinary approach has already been used in some of the bioeconomic research programs at the Centre in Dhauli.

Microlevel economic research is useful at the beginning to spread the technology among the fish farmers. But it is also very important to know the economic problems associated with the new aquaculture technology, such as whether the country can absorb the supply created by the enhanced production levels, which will affect fish price and farm income, and consequently affect further production and the impact of the technology. Therefore, it is necessary to study the demand projections at the micro and macro level. Besides certain problems associated with the spread of new technology to the farmers, there exist legal and sociopolitical aspects of land and water use for fish culture. Prominent among them is multiownership of land, which prevents interested fish farmers from undertaking intensive fish culture if any of the owners objects. Suitable legislation is needed to alleviate this problem by providing certain safeguards to the interested fish farmers to undertake new fish culture technology and by giving compensation to noninterested parties. Another major problem faced in India is that the fishermen are very poor and not in a position to obtain the capital needed for fish culture technology. The flow of credit through commercial institutions, perhaps through a State guarantee toward collateral security and marketing aspects of the produce, may to some extent remove constraints to faster development of fish culture in the country.

The constraints listed above are based on the authors' field trips in West Bengal. There is a great need to conduct surveys in the rural areas to determine the general and regional impediments to the adoption of the new aquaculture technology. Perhaps this is one field where further socioeconomic research can be undertaken such as has already been done for certain agricultural crops like rice.

Discussion

Farmers have been observed to adjust the stocking ratio depending upon the relative prices of the species to be stocked. In the experimental projects, 30–40% surface feeders, 30% mid-level feeders, and 30–40% bottom feeders were used depending upon the pond environment.

It was suggested by the participants that data on other variables, besides feed, be taken into consideration so that output variation could be explained as a function of several explanatory variables. Because the data on other variables, such as stocking rate, fertilization, and pond preparation, were observed to be within a certain range of application, the presentation of the relationship between feed and output assumes all other variables are given. If it were possible to collect more data on these variables from a sample of the cooperating farmers, it might be possible to explain a larger percentage of output variation.

General Discussion

The major issue raised in the discussion was the interaction between biologists and economists. At what stage of technology development should economic analysis be undertaken?

From the biologist's point of view, experiments are performed, production data are developed, and the system is optimized with the objective of maximizing output. The biologist provides the coordinates of the maximum production, but the economist needs a whole series of points to determine the relationship between input and output at different stages of production. This allows the economist to determine the optimum position in terms of maximum profits.

On the one hand, economic analysis of experimental systems that are just beginning is clearly premature. On the other hand, these are the type of projects in which in the past economists (and other social scientists) have been involved at too late a stage. It was suggested that the appropriate time to involve economists is when the technology is ready for pilot testing. At the technology generation stage, the biologist takes the primary role. As development progresses, and the technology is verified either under experimental conditions or in farmers' fields, the economist has the primary responsibility to determine the viability and adaptability of the technology. It was also suggested that sociologists and policymakers should actively participate, particularly in the transfer of the technology from the research station and field trials to the actual farmers' fields.

There is no simple answer to the question of timing of the approach. The development process can be divided into: (1) invention (the discovery of new techniques); and (2) innovation (where improvements are sought in existing systems). In the former, biologists are dealing with new frontiers and it is important that funding agencies take risks when private capital markets choose not to do so. At an early stage in the process of "invention," biologists become aware of important components of cost (labour or feed, for example), and as they seek to reduce these costs they are intuitively responding to the effects of the scarcity of the input in question. At this stage, economics is a guide rather than a tool for resolving the financial and economic status of the new technique in a definitive fashion. Pilot testing can then proceed and feedback can be used to reshape and adapt the production process to particular local conditions. Once these necessary conditions are met, field tests can demonstrate if the sufficient conditions can be met. As "innovation" begins, the role of the economist becomes more prominent.

The costs of bringing the economist and the biologist together are high, and, thus, two alternatives for cost effectiveness may be considered: (1) provide the biologist with some of the tools for economic analysis; and (2) hire an economist at certain stages of the technology development process.

Several participants, however, argued for the involvement of economists at an early stage in the analysis of time-series data from experimental projects or private farms so that they could develop production functions along the lines of those most often developed from cross-sectional data. It was pointed out that economists must do more than descriptive costs and returns, because this does not address the question of how to allocate scarce resources. Rather, attempts must be made to explain productivity and profitability.

It was also suggested that if biologists could provide data on various input combinations that are technically efficient (adding points to the isoquant), the economist could determine which combination was economically efficient depending upon the prevailing input prices. That is, the least-cost combination to produce a given output level could be determined.

It was suggested that a manual for bioeconomic analysis of aquaculture production systems be prepared using inputs from both economists and biologists. Identification and standardization of quantitative measures/indicators must be covered. If not carefully defined, the different measures can be confusing. Even if dollars, for example, are used, measures are not necessarily comparable because of differences in the price and income structures in different countries. Likewise, when choosing indicators, the scarce input in a particular country must be identified.

Session III
Socioeconomics of Aquaculture

Socioeconomics and Aquaculture: Informal Presentations

The overall session was presented in two parts. The first consisted of informal presentations and discussions of socioeconomics and aquaculture and, in the second, Theodore Panayotou gave a paper on social welfare economics and aquaculture. In this first part, Theodore Panayotou gave an introduction to the overall subject of the socioeconomics of aquaculture, highlighting the distinction between socioeconomics and social welfare economics. Aida Librero presented findings from some recent socioeconomic research in the Philippines and Sunimal Fernando discussed the role of sociology in research on socioeconomics and aquaculture.

Theodore Panayotou explained that two distinct interpretations may be given to the concept of "socioeconomics": one is the "amalgamation of sociology and economics"; the other is "social welfare economics." He suggested that social science research in Asian aquaculture has been mostly of the first variety and that there have been very few strictly economic studies on the subject and to the best of his knowledge none in social welfare economics.

The apparent intermixing of social relations and economic activities in developing countries and the consequent inability of economics to adequately explain observable "economic" behaviour had, in his view, led to the amalgamation of sociology and economics into what has come to be known as "socioeconomics." He also felt that the absence of established socioeconomic principles was partly responsible for the increasingly descriptive nature of socioeconomic research.

Normally, he said, socioeconomic studies begin with a detailed description of the sociodemographic characteristics of the sample (or population) under study. Such factors as family size, age structure, religious beliefs, and educational attainment are among the variables considered. The focus is on overall household incomes rather than profits from a particular economic activity because of the importance of family labour earnings at the subsistence level and the multiplicity of economic activities in which a small-scale farmer is often engaged. Home consumption of own produce and earnings in kind are imputed as "noncash income" and added to cash earnings to arrive at the total household income, which is then divided by family size to obtain income per capita, an indicator of well-being. He also explained that some studies use supplementary or alternative indicators of levels of living such as food expenditure as a percentage of total consumption expenditure, nutritional status, acquisition of consumer durables, educational levels, and other "quality-of-life" variables. Public services, social amenities, and community life may also be considered.

While many socioeconomic studies stop here, void of analytical content and policy implications, he reported that some do attempt to explain income levels or living standards using both economic and social variables, such as factors of production, prices, educational levels, religious beliefs, social relations, and access to political power. As a specific example, he said there have been some very fruitful socioeconomic studies of the constraints to the adoption of new technologies by small farmers in Asia.[1]

Panayotou reported that, unfortunately, very few analytical socioeconomic studies have been done in the area of aquaculture. Because there are many descriptive studies that provide useful background information on the socioeconomic conditions and farming practices of fish farmers, he suggested that future research should focus more on explaining rather than describing observed behaviour and prevailing conditions. Existing socioeconomic studies could provide useful baseline information for such research, especially in the case of the Philippines where

[1]See for example, International Rice Research Institute. 1977. Constraints to high yields on Asian rice farms: an interim report. International Rice Research Institute, Philippines.

detailed country-wide surveys have been undertaken over a number of years.

Aida Librero then provided a summary of the recent research studies in the Philippines, focusing largely on the sociology and economics of aquaculture. (The selected bibliography in this book includes many of these studies, which cover a range of aquaculture species such as milkfish, prawns and mussels.) These studies have also covered various techniques of production such as pond culture, pen culture, and sea farming. Specifically, the studies have looked at: (1) productivity and financial analysis of fish culture technology; (2) relationships between farm size and productivity; (3) market structure, conduct, and performance for fish; (4) comparative analysis of incomes of fish farmers and other components of the rural sector of the economy; and (5) levels-of-living analysis for fish farmers.

She stated that further research is still needed on the effects of technology on income and income distribution, and that research on resource management of the mangrove ecology should be given high priority because of the wide range of economic pressures that are being placed on this resource by competing uses.

This summary was followed by a discussion by Sunimal Fernando on the role of the sociologist and sociology in aquacultural research. He asked if the objective of our combined intellectual efforts in changing aquaculture production technology was to maximize production and income or to maximize social welfare? If the answer is the former, then the role of the sociologist is very limited, but if it is the latter, the sociologist's role is large and essential. The sociologist can define those variables and their relative importance or weights in the social welfare function and from that information hypothesize on some of the nonbiological and financial effects of the introduction of new aquacultural technology.

He also cautioned against the indiscriminate use of mathematical models that are used without full consideration and understanding of the complexity of social or community characteristics and relationships.

It was suggested that a continual two-way dialogue be encouraged between the researcher and the intended user or beneficiary of the technology during the research project.

Discussion

In the discussion that followed these three presentations, the following major points were raised:

- At any one time, the economist cannot solve the question of how best to maximize social welfare as a result of technical innovation, but can hypothesize and identify (beyond the known private costs and benefits) the broad effects of change.
- Perhaps social welfare economics requires placing relatively greater emphasis on the sociology and economics of the different groups in the analysis, i.e., economics and sociology on the individual farm household, economics on the agricultural sector, and sociology on the rural sector.
- Depending on the biological problem, innovation, or production system being researched, the range of disciplines to be involved and the phasing of their input into the overall research program will differ. An example was given of the exploitation of a mangrove swamp. There is no way to prescribe a strict rule on who will be involved, or when they will be involved in an aquaculture research program.
- Further thought must be given to how these various disciplines can be integrated in practice into specific aquaculture research programs.

Social Welfare Economics and Aquaculture: Issues for Policy and Research

Theodore Panayotou[1]

This paper reviews the basic concepts of welfare economics and focuses on market failures and possible remedies. It is aimed at noneconomists and provides examples of market failures from aquaculture and suggests areas where policy changes and research are necessary. Aquaculture in Asia and Southeast Asia is characterized as an infant industry that requires a major research effort coupled with government assistance to realize its full potential. It is suggested that these efforts, however, should be confined to those areas where the market fails to produce a socially optimal allocation of resources.

While it is generally acknowledged that there is a considerable potential for aquaculture in the region, the industry has been growing at a rather slow pace. In Thailand, for example, of an estimated 1.25×10^6 ha of mangrove swamps, tidal flats and estuarine areas suitable for fish culture only 17 000 ha were used in 1977. Catfish culture, again in Thailand, has been stagnating for the past decade despite rising catfish prices. The slow growth of aquaculture is all the more surprising at a time when fish supplies from natural sources are dwindling due to overfishing, pollution, and rising fuel prices while fish demand continues to rise under the pressure of increasing population, income growth, and urbanization. Meanwhile, governments and international development and funding agencies are in the process of implementing or designing assistance programs (subsidies, low-interest credit schemes, research and extension etc.) to accelerate aquaculture development. Yet, few of the past assistance programs for fish farmers can claim much success.

Two related questions arise in this connection: (1) What are the factors constraining the realization of the full potential of aquaculture? (2) What are the appropriate areas for government intervention?

Presumably, if fish farming is profitable at all it will be taken up without government intervention. If it is not profitable, it is not worth pursuing anyway and should not be encouraged unless there are potential net benefits for the society as a whole not captured by the individual producer. Such a discrepancy between social and private benefits and costs may arise from a failure of the market to register the true scarcity value of an input or output either because of the nature of the good itself or the imperfection of the market. For example, not all the benefits from infrastructure development or research into artificial spawning and disease control can be captured by the individual fish farmer but he would have to pay the full cost of the research if he decides to undertake it. Similarly, a distorted market may encourage the use of too much capital and too little labour in a developing country with scarce capital and abundant labour. In such cases, government intervention is warranted to correct what is known as a market failure.

A second scope for government intervention relates to income distribution. If the prevailing distribution of income is deemed "socially undesirable" and aquaculture is seen as a means for improving income distribution the government may provide assistance to the sector in general or to small fish farmers in particular. For instance, coastal aquaculture is seen today as a possible source of supplementary or alternative employment opportunities for impoverished small-scale fishermen. A third justification for judicial use of development assistance is provided by the infant state of the industry and the ensuing risks and uncertainty that form another market failure to the extent that they are higher for the individual than for the society as a whole.

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Social welfare economics is the branch of economics that takes the point of view of the society as a whole. It spells out the conditions under which social welfare is maximized and it examines how efficiently the market system works and how well it achieves the social welfare maximum. Because most real world market economies violate some of these conditions, a considerable part of welfare economics is devoted to the study of market failures and their effect on social welfare.

The objective of this paper is to review some basic concepts of social welfare economics, with emphasis on market failures, and to provide some examples of their relevance to aquaculture development. The purpose is neither to provide an exhaustive treatment nor to test the significance of market failures and related constraints in aquaculture but merely to stimulate discussion on these issues and encourage research in this direction. The exposition is kept at a nontechnical level because it is addressed primarily to noneconomists.

Optimality and Failures of a Free Market

In market economics intervention by the government (and by international development agencies) is justified only if a free market fails to allocate resources in such a way as to maximize the well-being of the society as a whole (social welfare). Government programs and international workshops to promote aquaculture (or any other sector) constitute a misallocation of resources unless they are directed at correcting or mitigating specific market failures. It is, therefore, of great interest to determine under what conditions a free market succeeds in efficiently allocating resources to maximize social welfare and under what conditions it fails to do so. This question can be answered in two steps: (1) Under what conditions does a free competitive market in equilibrium (general competitive equilibrium) attain maximum efficiency (Pareto optimum) in the allocation of the society's scarce resources? (2) Under what conditions is maximum efficiency sufficient for maximization of social welfare (social welfare maximum)? To answer these questions it is necessary to define more precisely the concepts of general competitive equilibrium, Pareto optimum, and social welfare maximum.

A general competitive equilibrium is a set of prices (and corresponding quantities) for all commodities and resources that clears all markets (demand–supply) when: (1) individual consumers choose their preferred basket of goods subject to their budget constraints determined by their initial endowment of resources and the resource and commodities prices; and (2) individual producers freely maximize their profits subject to the production technology and prevailing input and output prices. A competitive equilibrium exists for any distribution of wealth (initial endowment of resources) provided that all consumers have something of value and there are no indivisibilities.

Any change that makes at least one person better-off without making anyone else worse-off is an improvement of social welfare. A situation where it is not possible to make at least one person better-off without making someone else worse-off is called the Pareto optimum. To attain a Pareto optimum three conditions must hold:

(1) Efficient allocation of goods among consumers, which requires that the marginal rate of substitution between any pair of goods[2] should be the same for all consumers; otherwise we could make a consumer better-off without making anyone else worse-off through redistribution of goods;

(2) Efficient allocation of resources among producers, which requires that the marginal rate of substitution between any pair of resources[3] (inputs) should be the same for all producers who use both inputs; otherwise we could produce more of one commodity without producing less of another through reallocation of resources among users; and

(3) Optimal composition of output, which requires that the marginal rate of transformation between any pair of goods[4] in production should be equal to the marginal rate of substitution between the same pair in consumption for every individual who consumes both goods; otherwise we could improve social welfare by simply changing the composition of output.

A social welfare maximum is a situation where no conceivable change can improve social welfare given the society's resources and the state of technology. A Pareto optimum is a social

[2]The marginal rate of substitution of good X for good Y (in consumption) is the number of units of Y that must be sacrificed per unit of X gained to maintain a constant level of satisfaction.

[3]The marginal rate of substitution of resource A for resource B (in production) is the number of units of A that must be released per unit increase in B to maintain a constant level of output.

[4]The marginal rate of transformation of good X into good Y is the number of units by which the production of X must be decreased to increase the output of Y by one unit.

welfare maximum only if the corresponding distribution of wealth is "socially acceptable." While there are an infinite number of Pareto optima, each corresponding to a different distribution of wealth, there is a unique social welfare maximum corresponding to the most socially desirable distribution of wealth.

A competitive equilibrium is also a Pareto optimum provided there are no market failures[5] such as externalities, indivisibilities, increasing returns to scale, public goods, market imperfections, transaction costs, unpriced resources, or a lack of well-defined property rights. A competitive equilibrium is also a welfare maximum provided that the prevailing distribution of wealth is socially acceptable. If the above conditions hold, individual consumers and producers acting in their best interest (unknowingly) act in the best interest of the society (maximum social welfare). In such an "ideal" world, all worthwhile opportunities are utilized and all worthwhile exchanges have taken place; therefore, it is not possible to increase total satisfaction by redistribution of goods and wealth, reallocation of resources, or change in output composition. Under such conditions, there is very little room for government intervention except for the maintenance of law and order.

If the world we live in were perfect, we could simply rely on market mechanisms alone to allocate resources between aquaculture and other sectors and within aquaculture itself. There would be no unutilized opportunities for expansion of aquaculture and any attempt on our part to promote or discourage aquaculture would cause a misallocation of resources. With perfectly functioning markets and an acceptable distribution of wealth both aquaculture development and aquaculture research would be at their optimal levels at all times.

In the real world, in general, and in the developing world, in particular, market failures do exist and are in many cases pervasive. Some of these failures require modification of the conditions for Pareto optimality, whereas others completely destroy it. That is, even a second-best situation is not attainable. All, however, require some form of government intervention. We discuss only those market failures that are currently affecting, or are likely to affect in the foreseeable future, the development of aquaculture in the region.

[5]In the absence of market failures, utility-maximizing consumers and profit-maximizing producers set, respectively, the marginal rate of substitution and the marginal "rate of" transformation between any two goods equal to their price ratio. Because under competition all consumers and producers face the same price ratios, conditions (1) and (3) above are satisfied. Condition (2) is also satisfied because all producers set the marginal rate of substitution between any two inputs equal to their price ratio, which is identical for all producers.

Insecurity of Land Tenure, Multiple Ownership, and Common Property

One of the conditions for a competitive equilibrium to be Pareto optimum is a completely specified form of ownership (property rights) or control over all resources in the economy. Insecurity of land tenure, multiple ownership, and common property resources are clear violations of this condition and call for some form of corrective intervention.

Insecurity of land tenure is said to exist when an individual's ownership or possession of a particular piece of land is uncertain, in dispute, or under a short-term lease. Because investment involves an outlay today and a stream of benefits stretching over a long period of time, insecurity of tenure makes these benefits uncertain (while the outlay is certain) and, thus, discourages investment. This is certainly true of aquaculture, which requires a relatively high capital investment in the form of constructing ponds, dykes, and shelters right from the start while the benefits from this investment are earned over a number of years. The fear of expropriation by the state has similar effects on investment.

There are several examples of insecurity of tenure hindering aquaculture development in Southeast Asia. In Northeast Thailand, where 51% of the agricultural land has no ownership title (1977), farmers are reported to be reluctant to invest their limited savings in either land improvements or pond construction from fear that they will not be allowed to reap the full benefit of their investments (see Kloke and Potaros 1975a). In fact, investment itself increases the value of land and attracts the attention of the other claimants of the land (in this case, the government because most of the untitled land is in reserved forest areas or other public lands). Another example is offered by the case of disused mining pools in Malaysia; the 1-year Temporary Occupation Licence (TOL), or the lack of it, altogether discourages the pond improvements and high stocking rates required for an otherwise profitable intensive culture (see Bakar and Arshad 1980).

Multiple land ownership, however secure, has detrimental effects on investment analogous to those of insecure tenure. No single joint owner has sufficient incentive to invest in land improvements when he or she knows that all the other co-owners have a right to the benefits that accrue from this investment. Joint investment is a solution provided that the joint owners can agree on the type, scale, and financing of the investment. The larger the number of owners, the smaller is the likelihood that they will reach a stable agreement. Multiple ownership may even discourage the use of jointly owned land altogether.

A classic example is provided by some 500 000 tanks and ponds covering over 68 000 ha of land in Bangladesh that remain largely unused or underused despite an apparent potential for fish culture (see Khan 1981). Widespread multiple ownership, aggravated further by inheritance, is suspected to be a major constraint to the proper utilization of these ponds (see FAO/UNDP 1977) although other constraints may also be in operation. A similar situation prevails in Northeastern Thailand with large water tanks and reservoirs known as village ponds.

Common property, or open-access, is an extreme case of multiple ownership whereby every citizen in a country is a joint owner of the resource. Common property not only inhibits development but also inspires "exploitative" or destructive behaviour, as the bleak situation of the capture fisheries worldwide demonstrates. "Everybody's property is nobody's property," therefore, no single individual or group of individuals have enough incentive to either improve or manage the commonly owned resource. In fact, individuals have every incentive to deplete the resource as soon as possible as they have no guarantee that whatever they leave unharvested today will be available to them tomorrow. However, common property leads to "overexploitation" only when the resource can be exploited without the need for prior investment in resource development (e.g., capture fisheries). When such prior investment is necessary and its control is inextricably linked to the control over the resource, common property leads to underutilization of the resource. This is, in fact, not different from what happens with any resource owned in common: naturally occurring usable resource stocks are overexploited while no one takes action to enhance the stock.

Unfortunately, the areas where aquaculture has its greatest potential at present are the commonly owned tidal flats, mangrove swamps, estuarine areas, and inland waterbodies such as rivers and canals, large impoundments, and irrigation tanks. Although most of these areas either have no alternative uses or have uses that are compatible with aquaculture, very little has been done to realize their potential. In Thailand, for example, it has been estimated that there are 1.25×10^6 ha of mangrove swamps, tidal flats, and estuarine areas suitable for fish and mollusc culture of which only 17 000 ha were used in 1977 (see ADB 1978). Similarly, in Bangladesh it has been estimated that there are some 184 000 ha of "derelict" tanks and ponds with unexploited aquaculture potential (see Khan 1981).

The overall consequence of insecurity of tenure, common property, or multiple ownership of land suitable for aquaculture is that the market mechanism may allocate too little labour and capital to aquaculture and too much to capture fisheries and to agriculture. Possible solutions include land reform, long-term licencing, establishment of single ownership, auctioning of property rights, and promotion of cooperatives in the case of nondivisible multiple ownership.

Externalities

Common property resource problems are a special case of a more general market failure known as externalities. A common resource is overexploited or underdeveloped because each of the many owners imposes an externality on all other owners, a social cost that he or she does not pay and, therefore, can afford to ignore. In general, an externality is an effect of one firm's or individual's actions on other firms or individuals who are not parties in the activity. For example, the production of smoke from a factory may reduce the production of clean clothes by a laundry; similarly, the effluents of the same factory into a river may reduce the production of fish by downstream fish farms. The presence of such effects violates the Pareto optimality of the competitive equilibrium, which requires that economic units interact only through their (aggregate) effect on prices.

From the point of view of the recipient, externalities may be beneficial (external economies) or harmful (external diseconomies) and may occur either in production or in consumption. Here, we are mainly concerned with production externalities. Usually, we express a production function as a relationship between inputs used and output obtained. In the case of aquaculture, it is a relationship between the amount of inputs such as fry, feed, fertilizer, medicine, fuel, labour, and pond size, on the one hand, and quantity of fish produced, on the other. These are inputs the farmer made a deliberate decision to use in specified quantities. However, often we are unable to explain a considerable part of the variation of yield among farmers despite the inclusion of all conceivable inputs. The explanation may lie in the presence of significant production externalities, which are said to exist when the output of one farm is a function not only of its own inputs but also of the inputs and outputs of other farms. Externalities may be positive or negative depending on whether they raise or reduce the output (or profits) of the affected farm.

In the case of aquaculture, externalities take a particularly harmful form for downstream farms: their output and profits suffer from water pollution and contamination by upstream farms that use the water source for waste disposal at no charge. As a result, water quality is poor and fish diseases spread rapidly among farms using a common water source increasing mortality or raising production cost (use of medicine, need for more frequent water changes, etc.). Although the existence of the problem is not disputed, research is needed to quantify its effect on productivity and profitability, and government intervention is needed to enforce corrective measures.

Let us consider an example of how the problem of externalities might be formulated. Consider the case of a rice farm using agricultural chemicals such as pesticides and insecticides, operating upstream from a fish farm. The rice farm produces rice, R, from land, L_R, and from agricultural chemicals, X, according to a production technology:

$$R = g(L_R, X)$$

where $\partial g/\partial L_R > 0$ and $\partial g/\partial X > 0$.

The agricultural chemicals spill into the water source that is used by the downstream fish farm to produce fish (F) according to the amount of land, L_F, it employs and the amount of pollution, z, in the water, which depends on the amount of insecticides and pesticides, X, used by the upstream rice farm:

$$F = h[L_F, z(X)]$$

where $\partial h/\partial L_F > 0$, $\partial h/\partial z < 0$, and $\partial z/\partial X > 0$.

The rice farm maximizes its profit by using land and chemicals at such levels as to equate the value of their marginal products to their respective prices, r and w:

$$p \frac{\partial g(L_R{}^0, X^0)}{\partial L_R} = r$$

and

$$p \frac{\partial g(L_R{}^0, X^0)}{\partial X} = w$$

where p is the price of rice.

Unlike the rice farm, the fish farm does not control all the inputs into its production process. It takes the level of pollution in the water as parametric (beyond its control) and employs land at the level that equates the value of its marginal product to its rental price.

$$q \frac{\partial h[L_F{}^0, z(X^0)]}{\partial L_F} = r$$

where q is the price of fish.

Such a situation cannot be socially optimal. Obviously the production of rice (more specifically the use of chemicals in the production of rice) has adverse effects on the production of fish, but this is not taken into account by the rice farmers. From the society's point of view, "too much rice" and "too little fish" are being produced.

The socially optimum mix of rice and fish would be the one produced in the absence of externalities. One way to internalize the externalities is by merging the rice farm and the fish farm into a single economic unit that would attempt to maximize the combined profits, Π:

$$\max \Pi = p.g.\ (L_R, X) + gh[L_F, Z(X)] - r(L_R, L_F)$$

The joint rice-fish farm will maximize overall profit by using land chemicals according to the following decision rules:

$$p \frac{\partial g(L_R{}^*, X^*)}{\partial L_R} = r$$

$$q \frac{\partial h[L_F{}^*, z(X^*)]}{\partial L_F} = r$$

and

$$p \frac{\partial g(L_R{}^*, X^*)}{\partial X} + q \frac{\partial h[L_F{}^*, z(X^*)]}{\partial z} \cdot \frac{\partial z(X^*)}{\partial X} = w$$

The first term on the left-hand side (LHS) of the last equation is the value of the marginal product of pesticides/insecticides in rice production. The second term, which is negative because $\partial h/\partial z < 0$, represents the value of fish lost as a result of the use of pesticides/insecticides in rice farming. Thus, this equation states that the socially optimal level of pesticide use is lower than the level indicated by its marginal productivity in rice production, which guides profit maximization when the two farms operate individually. Not only $X^* < X^0$ but also $L_R^* < L_R^0$ and $L_F^* > L_F^0$ because with less pesticides/insecticides the productivity of land will be lower in rice production and higher in fish production. As a result less rice and more fish will be produced when the externalities are taken into account than when they are ignored. The reverse occurs when an external economy exists. For example, the use of fertilizer by an upstream rice farm may induce growth of natural feed in downstream fish farms; ignoring this externality results in the production of too little rice and too much fish. Hence, in the presence of externalities, profit-maximizing behaviour in a competitive market does not lead to the socially optimal allocation of resources.

There are several ways to remedy the failure of the market mechanisms to deal with externalities. First, offending inputs (or outputs) may be taxed to bring their private price, w in our example, up to the level of the social price, $w + q \cdot \partial h[L_F, z(X)]/\partial X$. In the case of external economies a subsidy could be introduced to lower the price of input (or output) with the beneficial externality. The problem with this method of correcting externalities is that often it is difficult to determine the optimum tax unless the precise technological interactions between the originator and the recipient of the externality are known.

A second solution is to set up a market for pollution, the unpriced output of the rice farm. The equilibrium price of pollution will be obviously the maximum amount that the fish farm will be willing to pay the rice farm upstream for a marginal decrease in pollution, that is, $q \cdot \partial h[L_F, z(X)]/\partial z$, which is the amount by which its profits will increase as a result of the marginal reduction in pollution. Thus, the equilibrium price of pollution is equal to the optimal tax, but the distributional implications are different. As long as the externality is private (only one rice farm and one fish farm) the recipient has an incentive to bribe the originator to decrease the production of external diseconomies and increase the production of external economies. When, however, the externality is a public good (many rice farms and many fish farms), no individual fish farmer has sufficient incentive to bribe thousands of rice farmers to reduce pollution, while concerted action by all fish farmers will not work because each has the option to be a "free rider." As we will see in the next section, in this case public goods markets do not work.

A third solution calls for rearrangement of property rights, that is, the merging of the originator and the recipient of the externality into a single ownership. Again, in the case of a private externality, there is incentive for such action: because the profits from a combined operation (Π^*) are larger than the combined profits of separate operations ($\Pi_R^0 + \Pi_F^0$) it always pays the one farm to buy out the other. However, when the externality is public there is not sufficient private incentive for such rearrangement of property rights.

In an analogous manner one can deal with the problem of two fish farms, each of which imposes external diseconomies on the other by releasing contaminated water into their common water source. To maximize social benefit the combined profit of the two farms (rather than the profit of each) should be maximized:

$$\max \Pi = qF_1 + qF_2 - C_1(F_1, F_2) - C_2(F_1, F_2)$$

where Π is profit, q is the price of fish, F_1 and F_2 are the quantities of fish produced by farms 1 and 2, and $C_1(\cdot)$ and $C_2(\cdot)$ are their respective cost functions. Combined profits are maximized by setting:

$$\frac{\partial C_1}{\partial F_1} - \frac{\partial C_2}{\partial F_1} = q$$

and

$$\frac{\partial C_2}{\partial F_2} - \frac{\partial C_1}{\partial F_2} = q$$

The first term on the LHS of these two equations represents the cost of producing the last kilogram of fish in each farm, whereas the second term represents the cost imposed on the other farm through water contamination resulting from the production of this additional kilogram of fish. Again, the market mechanism may work out a solution as long as the externality is private, or at least concentrated, and important enough for the "internalization" benefits to be apparent to all parties involved. When the external effects are too widely spread the correction of the externality is a public good, in which case, as we will see below, the market mechanism does not effectively function and government intervention is necessary. It must be stressed, however, that not all externalities are worth correcting and there are few that are worth eliminating entirely: the guiding principle should be that the gains in social welfare from correcting an externality should outweigh the costs of the intervention.

Public Goods

When several originators and recipients are involved, externalities, such as water and air pollution, may be considered as public "bads" and their correction as a public good. In fact, a public good may be thought of as an extreme case of a good that has only externalities, that is, no part of it is private to any individual. Each individual's consumption of such a good depends on the total quantity of the good supplied in the economy. Unlike the case with private goods, the consumption of a public good by an individual does not diminish its availability to other individuals. Although the production of public goods involves an opportunity cost in terms of foregone quantities of private or other public goods, a zero opportunity cost is associated with its consumption.

A public good is characterized by jointness in supply, in that to produce the good for one consumer it is necessary to produce it for all consumers. In many cases, no individuals can be excluded from the enjoyment of a public good (e.g., national defence) whether they pay for it or not. However, even if exclusion is possible (e.g., a bridge across a river), to do so violates Pareto optimality, which requires that no opportunity of making one person better-off without making anyone else worse-off is left unutilized. Because nobody can or should be excluded from the benefits of a public good, consumers would not freely pay for it and, hence, no firm would be able to cover its production cost through the market; hence, the market mechanism would fail to supply a public good, although it would contribute to social welfare. Thus, competitive equilibrium will lead to underproduction of public goods and overproduction of private goods.

The conditions for Pareto optimality are not valid in the case of public goods. Recall that for private goods the condition for optimality was that the marginal rate of substitution of each consumer between two goods, X and Y, should be equal to that for any other consumer and to the marginal rate of transformation between the two goods ($MRS^1_{XY} = MRS^2_{XY} = \cdots = MRT_{XY}$). When one of the two goods is public, optimality requires that the sum of the marginal rates of substitution of all consumers be equal to the marginal rate of transformation ($MRS^1_{XY} + MRS^2_{XY} + \cdots = MRT_{XY}$). In this case, MRS^1_{XY} indicates how much of the private good X consumer 1 is willing to sacrifice to pay for one more unit of the public good Y. As such, the MRS_{XY} may be used as a measure of how much each consumer should be taxed to cover the cost of producing the public good. Thus, although all consumers consume the same amount of the public good they pay different "prices," whereas in the case of the private goods, consumers pay the same price but consume different quantities of the good.

Because individual consumers cannot adjust the amount of the public good they consume, a market for it cannot exist. For the government to provide a public good it is necessary to know each individual's marginal rates of substitution between the public and private goods, which would determine the optimal level of the public good and (perhaps) each individual's share of the cost. However, because consumers may not reveal their true preferences for fear that they may be taxed on the basis of their willingness to pay, public goods are usually produced by public agencies on the basis of collective decisions and financed from general taxation.

In aquaculture there are at least two important cases of public goods: (1) the correction of externalities such as widespread water pollution and the control of fish diseases, which cannot be internalized; and (2) research into new fish-culture technologies, including new breeding techniques, new feed formulas, and new methods of disease control and treatment. These two aspects of aquaculture development involve the production of public goods because a fish farmer's use of a pesticide-free water source, of a disease-free environment, or of a new more efficient input combination does not reduce their availability to other fish farmers. Without government intervention, the production of these public goods will be below their socially optimal level, if they are produced at all.

Decreasing and Increasing Cost Industries

A decreasing cost industry is one whose average cost falls as output rises. Decreasing costs occur where there are increasing returns to scale arising from indivisibilities. Decreasing costs may lead to monopoly if the scale economies are so significant that low-cost production requires a firm that is too large relative to the market (natural monopoly). Competition in a decreasing cost industry does not lead to Pareto optimality, because it is always possible to increase the production of the industry, without reducing the production of other industries, by simply reducing the number of the firms in the industry until one produces all the industry output at the lowest cost. Examples of decreasing cost industries are public utilities such as telephone, electricity, and water supply. In aquaculture, this variety of market failure may occur in relation to water supply and fry production and distribution, but it is rather rare.

The reverse, that is increasing cost, is more common in aquaculture. An increasing cost industry is one in which the average cost of production rises as the output of the industry rises. This increase in average production cost is due to the higher input prices that must be paid to attract additional quantities of inputs to the industry. This occurs when the supply of inputs used by the industry is not perfectly elastic (upward sloping), which means that the industry can expand only by paying higher input prices and, hence, by charging a higher price for its output (increasing industry supply price). Decreasing cost, however, does not lead to a market failure. In terms of allocative efficiency, the Pareto optimality of the competitive system remains intact. There are, however, distributional implications (income transfers from consumers to factory owners) that may bring the competitive equilibrium closer to or further from the welfare maximum. Another reason why decreasing cost industries are mentioned here is to emphasize the need for taking into account the effect of (a rapid) aquaculture expansion on input costs and, hence, average production costs, which is often ignored in aquaculture development plans with consequent overstatement of aquaculture potential.

To some extent, aquaculture, at its present level of development, exhibits the characteristics of an increasing cost industry. This arises from its overdependence on seed and feed from natural sources. For instance, further expansion of milkfish in the Philippines is almost certain to result in higher costs for fry, which are only available from natural sources (see Chong et al., in press). Similarly, the rapid expansion of catfish culture in Thailand during the late 1960s and early 1970s was partly responsible for the increasing price of trash fish (see Kloke and Potaros 1975b; Panayotou et al. 1981). Land, to the extent that it has alternative uses, may be another source of increasing cost, especially if extensive aquaculture expansion is undertaken.

A different source of "increasing cost" arises from the increasing occurrence and spread of fish diseases as the culture of a particular species in a given location expands. A classic example is the spread of catfish diseases in Suphan Buri Province of Thailand following the remarkable expansion of catfish culture in the area during the late 1960s and early 1970s (see Wattanutchariya and Panayotou, this volume). This last case is a market failure (externality) because it arises from the fact that individual new producers take into account only their production cost and ignore the fact that their entry into the industry raises the costs of existing producers by increasing the likelihood (and spread) of disease.

The "increasing cost" feature of aquaculture in its present stage of development, has the following implication for aquaculture research: unless technical breakthroughs in artificial spawning, feed formulas, and disease control occur to shift to the right the supply curve of inputs critical to aquaculture, the current production costs and profitability of aquaculture cannot be used as indicators of its potential for expansion without adjustment for the effect of new entrants on the industry costs.

Depending on the stage of development and type of aquaculture, increasing, constant, or decreasing cost may prevail. For instance, during the late 1960s catfish culture in Suphan Buri (Thailand) passed through a stage of decreasing production cost as the expansion of the number of farms enabled catfish producers to enjoy low-cost fry and feed as a result of economies of scale in their procurement and transportation.

Market Imperfection

The Pareto optimality of the competitive equilibrium rests on the assumption that all markets are perfectly competitive: a large number of firms sell a homogeneous product to a large number of buyers at the prevailing price without "discrimination." In reality, we observe economies ridden with monopolistic elements. A market is imperfectly competitive if the actions of one or a few sellers or buyers have a perceptible influence on price. Market imperfections may arise for a variety of reasons. We have already discussed indivisibilities as a cause of natural monopoly. Other causes may be institutional, legal, or political barriers to entry into certain professions or industries; high information costs may also limit competition or access to markets; and the (limited) extent of the market — a common problem in developing countries — may result in oligopolies/oligopsonies because only a few firms may supply the entire market. A usual monopolistic practice is to withhold supplies to raise prices. The monopolist's price is too high and his output too low for Pareto optimality. Market imperfections, in general, violate the Pareto optimality criterion that the producer's marginal rates of transformation should be equal to the consumer's marginal rates of substitution (this requires marginal cost pricing, whereas the monopolist uses average cost pricing).

In the early stages of aquaculture development, the extent of the market for various inputs, especially hatchery-produced fry and artificial feed, is likely to be quite limited. This coupled with the high technological input and substantial returns to scale may lead to some degree of monopoly in the provision of inputs to fish farmers. This is true, for example, of the animal feed industry in Thailand, and the same pattern appears to be emerging in the case of artificial fish feeds. Another possibility is monopsony in output marketing arising from the lack of a well-established marketing system for freshwater fish (e.g., Thailand) coupled with the dispersion of fish farms and the generally low reservation price of fish farmers (keeping the fish in the pond beyond the time it reaches harvesting size is costly in terms of feed, risk of disease, and delay of the next crop). However, the most common and effective safeguard of monopsony power in the case of aquaculture is credit-secured preemptive marketing arrangements. The fish farmer is particularly vulnerable to such arrangements because of the relatively high level of operating capital (especially for feed) required. As such, capital can rarely be obtained through institutional credit (commercial banks, financial trusts, cooperatives) and fish farmers have little choice but to obtain feed and other inputs on credit from middlemen by surrendering their option to choose the market outlet for their harvest. This leads us to a discussion of capital market imperfections, which are not only severe by themselves (especially in developing countries) but are at the root of many other input and output market imperfections.

Ideally, economic activities and business ventures that promise to yield a net return higher than the going interest rate should be able to obtain funds for investment because they expect to earn enough to pay the cost of borrowed capital and still earn a profit. In reality, this does not always happen. Unless the farmers already have sufficient property or capital assets to use as collateral, and unless they understand and are able to meet rigid repayment requirements, they cannot obtain institutional credit at the going rate of interest. Most farmers in developing countries, being either subsistence or small-scale commercial farmers, have access only to non-institutional credit that comes with high interest rates, usually a multiple of the institutional rate, and, more often than not, hidden debilitating marketing arrangements. This means that even if fish culture is profitable at the institutional rate of interest (say 15%) it may be unprofitable at the much higher (usually above 100%) cost of informal credit, often the only source of funds for the small farmer. Thus, unless the government makes collateral-free credit available to small farmers at the institutional rate of interest, much of the aquaculture potential cannot be realized. Although capital market imperfections affect all farming activities, they are particularly detrimental in the case of fish culture because of the relatively high initial capital requirements for pond construction and the substantial amounts of operating capital that are required.

Risk and Uncertainty[6]

The real world is not only beset by imperfections; it is beset by uncertainties. A situation is said to involve uncertainty if more than one outcome is (or is perceived to be) possible from any given action. Two types of uncertainty may be distinguished: (1) environmental uncertainty arising from factors beyond the decision-maker's (farmer's) control, e.g., weather, epidemic disease, technological discoveries, etc.; and (2) market uncertainty arising from a market failure to provide information (prices) required for decisions affecting the future (absence of future markets). The longer the time horizon (culture period in the case of aquaculture), the further into the future forecasts need to be made and the greater the uncertainties involved.

A distinction is sometimes made between uncertainty and risk. A situation is said to involve uncertainty if no objective probability to each of the many possible outcomes can be attached. In contrast, risk is a situation where the general level of probability of each outcome can be inferred although known probabilities cannot be precisely assigned. In everyday use, a situation is said to be risky if one of the outcomes involves losses to the decision-maker. Thus, the risk of loss to a firm or farm may be defined as the probability that profits will be less than zero, or the probability that returns will fall below some "disaster level" of income.

Risks may be reduced through diversification of activities with negatively correlated outcomes, ("putting all one's eggs in one basket" is rarely a good policy). Risks in one activity may also be

[6]In an economy with complete markets, the competitive equilibrium is characterized by an efficient allocation of risk-bearing leaving no room for government intervention.

reduced by pooling them with risks from other independent activities. Where risks are of a given type (e.g., independent of the actions of the decision-maker), risk-pooling or insurance markets have not failed to arise to exploit these possibilities. Individuals transfer their risks to an insurance company by paying an insurance premium, which in a perfect insurance market would equal the administrative costs of the company plus the cost of any remaining risk.

However, not all risks are insurable. Insurance markets fail to appear when the outcome is not external to the policyholder, the risks affect all policyholders in a similar way, or the probabilities of the various outcomes are difficult to assess. For example, a farm cannot insure itself against the risk of losses because profitability is as much a function of the farmer's actions as it is of environmental uncertainty (e.g., weather). Similarly, a fish farm cannot insure itself against the risk of an epidemic because such risk would affect all farms in a similar way, which reduces the benefits from risk-pooling.

Risks may be objective or subjective. Objective risks are calculated on the basis of the probability of occurrence of the adverse outcome. Subjective risks are based on a given individual's assessment of the probability or consequence of the adverse outcome. Attitudes toward risk differ among individuals based on sociocultural and economic factors. In general, risk aversion tends to be stronger among lower socioeconomic groups because survival is at stake.

Risk and risk aversion may affect aquaculture development in many ways. Subsistence rice farmers are unlikely to switch from rice to fish farming (even if the returns from the latter are higher) if they perceive that more risk is involved. This is quite likely because rice is a subsistence crop and fish is not. Fish must be sold at the market for cash and this cash used for the purchase of rice and other necessities. Moreover, unlike rice, fish is perishable and cannot be stored except at very high cost. The cash crop and perishability features of fish make the farmer vulnerable to the vagaries of the market. There are also technological risks: small farmers are unlikely to shift from a traditional crop (or technology) that they have come to know and trust over the years to a new one that promises higher yields but may also entail greater risks of crop failure, especially until they learn the new technology completely.[7]

[7]The two hypotheses, that risk aversion biases production in favour of subsistence crops and that poverty inhibits adoption of new technologies, although plausible, require empirical testing.

At its present stage of development, aquaculture remains a high-return, high-risk activity. This high noninsurable risk discourages both farmers and credit sources despite the high return: the subjective risk, for the small farmer, is even higher than the objective risk because risk-taking at a subsistence level of income may cost the farmer and family their survival. This risk looms particularly great when the large amounts of operating capital are considered in conjunction with the high probability of disease in the one or two ponds that the small farmer can afford. For those small farmers already engaged in fish farming, risks may act as a constraint to the intensification of culture or the adoption of new technologies.

There are a number of ways to reduce inefficiency brought about by risk aversion. One way is to reduce technological risks through research and extension. Another way is through a crop insurance program. However, the costs of financing and administering such programs are often too high relative to the risk-diffusion benefits unless distributional considerations are also brought into the calculus. A third policy option for dealing with risk aversion is to subsidize credit for small farmers who cannot obtain loans from institutional sources. Again the costs are high but, unlike crop insurance, subsidized credit may help "mitigate" capital market imperfections and reduce the disparities in the marginal products of capital across farms. Finally, if farmers tend to underproduce "risky" crops there may be scope for price support to produce a socially more desirable crop mix.[8]

Distributional Considerations

Up to this point we have discussed market failures that destroy the Pareto optimality (maximum efficiency) of the competitive equilibrium and call for government intervention. Now we will consider issues relating to equity. A competitive equilibrium, even if a Pareto optimum, fails to maximize social welfare when there is dissatisfaction with the distribution of wealth. As Adam Smith (1776) put it: "No society can surely be flourishing and happy, of which by far the greater part of the numbers are poor and miserable."[9]

The market mechanism gives rise to a distribution of welfare that depends, among other things, on the initial distribution of skill and

[8]For a detailed treatment of risk and uncertainty in agricultural development see Roumasset et al. (1979).

[9]From Todaro (1977), p. 94.

wealth. There is no reason why such a distribution would be socially acceptable. For example, the market mechanism would allocate very little or nothing to those who happen to be weak, ill, landless, or unemployed. That such people should starve for no fault of their own is socially unacceptable. Similarly, striking and ever-widening inequalities may conflict with our idea of distributive justice. The alleviation of poverty and the reduction of socioeconomic disparities often calls for government intervention to correct the "failure" of the market mechanism to produce a socially acceptable distribution of income. Such intervention would not interfere with allocative efficiency (Pareto optimality) if it is confined to "lump-sum" transfers, which in theory can achieve any desired distribution of welfare. However, lump-sum transfers do not always work in practice and sooner or later distributive measures that conflict with efficiency (e.g., progressive taxation) are introduced. Care, however, should be taken to minimize the sacrifice in efficiency required for attaining the desired distribution of income. In terms of efficiency, it is preferable to effect a change in the distribution of welfare through quantitative changes in factor endowments rather than through changes in relative prices that interfere with Pareto optimality (price ratios equate the marginal rates of substitution and transformation). In practice, it is easier to manipulate prices.

Although it is generally easier to improve income distribution in a growing economy than in a stagnant economy, without a deliberate action to channel a substantial part of the income increments to the poor, growth may exacerbate rather than reduce poverty.

The inclusion of redistribution objectives in the development plans of many South and Southeast Asian countries is indicative of social dissatisfaction with the prevailing distribution of welfare. In the case of aquaculture development, two main objectives are often stipulated, one relating to growth and efficiency and the other to distribution: (1) to increase fish supplies for the domestic and export markets; and (2) to provide supplementary or alternative sources of employment, income, and nutrition to subsistence farmers and small-scale fishermen.

To the extent that indivisibilities or economies of scale exist in aquaculture, it is more efficient to increase fish production by promoting large-scale farms. The high marketing costs of a perishable commodity may favour central locations to the neglect of isolated areas that are in need of additional employment opportunities. Underpriced capital and overpriced labour (see following section) may lead to socially unwarranted mechanization of aquaculture and the loss of employment opportunities in labour-surplus countries. Attempts to deal with localized externalities or to take advantage of economies in vertical or horizontal integration may lead to consolidation of landholdings and monopolistic markets (see for example, the poultry and feed industry in Thailand, which is presently expanding into fish farming).

Thus, the objective of rapid growth in fish supplies may be in conflict with the objectives of creating employment opportunities and reducing socioeconomic disparities. On distributional considerations, small-scale farms should be promoted, which requires credit on easy terms, technical assistance, and possibly the (free) supply of some inputs such as fry from government hatcheries. There is also a related conflict between production of high-value species for export and production of inexpensive species for domestic consumption. For example, Thailand divides its efforts between the promotion of large-scale commercial culture of luxury and semiluxury species, such as prawns and snakehead fish, and the promotion of employment, higher cash income, and better nutrition through the concept of the village pond (stocked with carps or tilapia) in poor areas, particularly the Northeast. On efficiency grounds alone, all efforts and funds should have been directed to the types of culture and locations with the highest return.

Thus, in allocating research or investment funds for aquaculture development, both efficiency and distributional criteria should be used with explicit tradeoffs when there is conflict. The state's distributional weights for different socioeconomic groups are often implicit in national development plans. These or other explicit weights should be used in comparing the distributional implications of alternative research, investment, or assistance projects.

Divergence Between Social and Private Costs and Benefits

The implication of market failures is that market prices do not represent true scarcities, that is, social opportunity costs. The implication of dissatisfaction with the prevailing distribution of welfare is that even when prices reflect true scarcities (Pareto optimum), they do not serve the society's objectives (welfare maximum). Therefore, allocation of resources based on market prices may not lead to maximization of social welfare.

Because the government is often unable to correct all market failures (e.g., public goods, widespread externalities, etc.) and secure the desired redistribution through taxation, it uses the allocation of investment resources through the political system to achieve its social objectives. Thus, the question arises: How are costs and benefits of alternative public projects to be calculated and compared? The answer lies in the computation of "social or shadow prices," which are determined by the interaction of true resource scarcities and social policy objectives.

In a perfect world, where a competitive equilibrium is also a social welfare maximum, shadow prices will be identical to market prices. Considering, however, the pervasive market imperfections in developing countries, a severe divergence may exist especially in the labour, capital, and foreign exchange markets. In the extreme case of a country with widespread chronic unemployment, the shadow wage rate (or social opportunity cost of labour) would be zero rather than the positive wage rate actually paid. If, in addition, reduction of poverty is among the society's objectives, and fiscal means are not effective, when a public project is expected to give employment and higher income to the poor, a further downward adjustment of the shadow wage rate should be made. Thus, use of the market wage rate would have resulted in underestimation of the net employment benefits from the project. In contrast, the market prices of capital and foreign exchange are far below their true scarcity values resulting in overestimation of the net benefits from their use.

A detailed exposition of the cost-benefit analysis of public projects is beyond the scope of the present review.[10] However, a few more cases of divergence between benefits and costs particularly relevant to aquaculture will be mentioned. Risk, although an important consideration in private calculations of costs and benefits, is almost negligible from the society's point of view, because the society automatically pools the risks from all economic activity. The social rate of discount or time preference is also likely to be lower than the private rate because risk and uncertainty, taxation, selfishness, mistaken optimism, and shortsightedness are less applicable to the society as a whole than to individuals. Moreover, taxes and subsidies, although part of private costs and benefits, are transfers involving no use of society's scarce resources (except to the extent that they interfere with the efficient allocation of resources). Finally, costs and benefits external to private operators are real costs and benefits from the society's standpoint and should be taken into account in calculating the social profitability of an economic activity or evaluating public projects.

What are the implications of all this for aquaculture? First of all, when we speak of aquaculture potential we should always make clear whether we mean private profitability, social profitability, or merely technical feasibility. If aquaculture of a particular type in a particular location is profitable to the individual operator but socially unprofitable (due to externalities, capital intensity, etc.) the government should discourage it through taxation, regulation, etc. If, on the other hand, aquaculture is socially profitable but unattractive to private investors, promotion through subsidies may be appropriate. Secondly, in labour-surplus economies, labour-intensive aquaculture should be promoted by subsidizing (or somehow inducing) private pond operators to employ more labour than they would on their own accord. Also, shadow prices should be used to evaluate public projects for the provision of basic infrastructure for aquaculture or for direct government involvement in aquaculture development where private investment is unavailable or undesirable (e.g., mariculture). Finally, in evaluating the social profitability of aquaculture, its indirect effects on other sectors of the economy should be considered. For example, aquaculture may facilitate the management of capture fisheries if it can provide fish at competitive cost and at the same time employ a significant number of the surplus fishermen, thus reducing both the attractiveness of and need for destructive fishing and allowing the government to introduce enforceable regulations for the recovery of the wild stocks. In any case, coastal aquaculture if profitable can serve as an alternative or supplementary source of income for coastal fishermen. Conflicts between culture and capture fisheries also exist as has been demonstrated by the reduction of catch in Laguna de Bay (Philippines) after the introduction of fish pens.

A Note on the Second Best

If the marginal conditions for Pareto optimality were satisfied both before and after the implementation of a public project and if markets were perfectly competitive, we would use market

[10]Good expositions of cost-benefit analysis are found in Winch (1971) and Squire and van der Tak (1975).

prices to calculate costs and benefits. In such a perfect world, projects should be implemented until the marginal unit had a private cost–benefit ratio of one. This implies equality of marginal benefit (price) to marginal cost, which is one of the conditions for the Pareto optimality of the competitive equilibrium. But price should be everywhere equated to marginal cost. If one or more of the marginal conditions for a Pareto optimum are violated (and correction of the distortion is not possible[11]), a first-best situation is not attainable and the satisfaction of the remaining conditions is not necessarily desirable. The best we can achieve is a second-best world that requires violation of the Pareto conditions; piecemeal policies based on the fulfillment of these conditions in a partial equilibrium context may reduce rather than increase social welfare.

Because we live in an imperfect world, the task of cost–benefit analysis is to evaluate second-best policies by allowing for suboptimality (externalities, monopolies, etc.) in the assessment of costs and benefits. Instead of private we use social costs and benefits and incorporate the "second-best constraints" of an imperfectly competitive, distorted, and uncertain world in their measurement. The first-best policy would attack the specific imperfections and distortions directly. But this is, by definition, impossible because of institutional constraints.

Concluding Remarks

The purpose of this paper was to review some basic concepts of social welfare economics for the noneconomist and to explore their applicability to aquaculture development. At least two important concepts, the compensation principle and the social welfare function, were not included for reasons of brevity and simplicity. The thrust of the paper is that a competitive market would result in the most efficient allocation of resources if there were no market failures and would maximize social welfare if the distribution of income was acceptable. In reality, there are several market failures and dissatisfaction with the prevailing distribution of income. The paper reviews the main market failures (externalities, public goods, etc.), points out the way in which efficiency is affected, and provides examples from aquaculture that may form the subject of future research. Forms of possible government intervention to correct or supplement the market mechanism are also discussed. Maximization of social welfare in an intrinsically imperfect world calls for the public sector to provide public goods, to mitigate the inadequacies of the market, and to promote a socially more acceptable distribution of welfare.

Throughout the paper examples are given of market failures affecting aquaculture development. It is of interest, however, to highlight here some problems facing aquaculture that are not so much the result of market failures as they are the consequence of the young age of the industry. Aquaculture is still a novelty with uncharted territory. Both on the consumption and production sides there are risks and uncertainties. In countries such as Sri Lanka and Malaysia, freshwater fish is not yet as popular as marine fish. In most Southeast Asian countries, with the possible exception of the Philippines, the marketing and distribution system for freshwater fish is not well developed. Moreover, fish culture poses marketing problems of its own because, unlike capture fisheries, the harvesting is concentrated in a few days of the year and, unlike field crops, fish is a highly perishable commodity.

However, aquaculture faces its most serious challenge on the production side. Biological and technical knowledge of many cultured species is relatively limited and of this only a small part reaches the farmer. The industry is still very vulnerable to changing economic conditions and outbreaks of little-understood diseases. Experience, as it has been learned from the case of catfish culture in Thailand, is the deciding factor between handsome profits and bankruptcy. Farmers have still to rely on trial and error to arrive at optimum stocking rates, feed formulas, and disease treatment. In short, aquaculture still has all the characteristics of an infant industry that requires a major research effort and government assistance if it is to realize its full potential. In designing research programs and government projects for promoting aquaculture in the region, the reviewed concepts of welfare economics may serve as a guiding framework.

The author acknowledges the valuable comments received from Keith Hay and the other participants in the workshop.

[11]In the absence of institutional constraints, it is possible to design a system of unit taxes and subsidies that would lead a market economy from a Pareto-suboptimal allocation of resources to a Pareto-optimal allocation and a system of lump-sum taxes and subsidies that will lead to the desired income distribution and, hence, to social welfare maximum.

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General Discussion

In the final summary discussion, the following key points were made:

• Economics must reassess private rates of return in light of the broader social costs and benefits. This social accounting must determine a new social rate of return and this must be compared with the rate of interest at which the government borrows money to invest in such development activities as aquaculture technology.

• The question of shadow pricing is important but often ignored. In many societies there are internal prices that bear little or no relation to international market world prices. As a technology such as aquaculture develops and becomes an industry exposed to the competitive effects of international supply and demand, its input and output prices increasingly reflect their real resource costs. Therefore, it is important to use world prices as the shadow prices during technology development so that the chances of the technology's future survival and growth will be enhanced.

• Demand and marketing aspects are important to assess in addition to the economics of production.

• The economic analysis presented during this workshop is best suited to the analysis of static situations or the economics of resource use at a particular point in time; it is weak in providing information and analysis on the process of change.

Conclusions and Recommendations

The following are six conclusions and recommendations reflecting major points of discussion in the workshop:

• Effective interaction between the biologist and economist is essential. This interaction is illustrated by the need to accurately identify and distinguish between the maximum points of biological production and economic profit. Almost without exception, the output level of maximum profit is reached before the biological maximum. However, there was no consensus as to when this interaction should begin.

• At the stage of initial experimental design and development of separate biological/technical components of a technology (for subsequent testing and evaluation) there was no consensus as to how and when economic analysis could be used. At the stage of pilot-scale testing and evaluation, the techniques of marginal and total cost-benefit analysis could be effectively and usefully employed. When testing and adapting the technology with a sample of target beneficiaries or users, then marginal and total cost-benefit analysis, partial budgeting, and the socioeconomic survey could be applied. When evaluating the economics of an existing production system, the whole range of economic tools could be used, including production and demand function analysis along with the other above mentioned techniques.

• Economic studies on existing aquaculture systems have tended to be descriptive rather than analytical. Future studies should attempt to be more analytical so as to provide more useful information on the sociological, technical, and economic constraints to increase productivity and profitability.

• Specifically, demand analysis and marketing were recommended as important areas for future aquaculture economic research in Asia.

• It was recommended that more farm record keeping be encouraged and introduced into aquaculture economic studies to improve the present "recall" technique for obtaining historical data.

• It was strongly suggested that the sociologist had an important role to play in research on existing production systems and in the development of new technologies but that a detailed discussion on this interaction was outside the focus of this workshop.

Appendix 1:

Working Definitions of Economic and Statistic Terms

AVERAGE FIXED COSTS: Total fixed cost divided by output.

AVERAGE (PHYSICAL) PRODUCT: The total (physical) product divided by the amount of the input used to produce this output.

AVERAGE TOTAL COST: Total cost divided by output.

AVERAGE VARIABLE COST: Total variable cost divided by output.

BENEFIT-COST RATIO: The ratio of the present value of revenues to the present value of costs.

BREAK-EVEN ANALYSIS: The level of price or production at which the project just covers its total costs.

CASH COSTS: Out-of-pocket costs for inputs incurred in producing an output. Sometimes, this is known as explicit costs.

COMMON PROPERTY: Is the lack of well-defined and enforceable property rights over a certain factor of production, e.g., coastal areas, estuaries, and fishing grounds in the open seas.

COMPETITIVE EQUILIBRIUM: Is said to exist when the markets for all inputs and outputs clear (no excess demand or excess supply exists) following a free choice by the consumers of their consumption basket subject to their budget constraint and a free maximization of profits by the producers subject to their production technology and prevailing market prices.

CONSTANT RETURNS TO SCALE: If all inputs are expanded in the same proportion, output is expanded in the same proportion.

DECLINING-BALANCE DEPRECIATION: A fixed rate (percentage) of the remaining value of the asset.

DECREASING COST INDUSTRY: Is one in which the average cost of production falls as output rises due to indivisibilities in certain factors of production.

DEGREES OF FREEDOM: Roughly speaking, it is the total number of observations or variates minus the number of estimated parameters.

DISCOUNTING METHOD: Conversion of future costs and revenues into present values.

ELASTICITY OF SUBSTITUTION: Elasticity of substitution shows the proportional change in the input ratio (for example, capital-labour ratio) induced by a given proportional change in the input price ratio.

EXTERNALITY: Is the effect of one firm's or individual's actions on other firms or individuals who are not parties in the activity, e.g., the use of pesticides by a rice farm may adversely affect the production of a downstream fish farm.

FIXED INPUT: An input whose quantity cannot readily be changed when market conditions indicate that an immediate change in output is desirable.

GEOMETRIC MEAN: The sum of the logarithms of the observed values, divided by the number of observations.

GROSS OR TOTAL REVENUE: Total product or output multiplied by the market price of output.

INCREASING COST INDUSTRY: Is one in which the average cost of production rises as the output of the industry increases, due to unresponsive (inelastic) input supply.

INCREASING RETURNS TO SCALE: If all inputs are increased by a certain proportion, this results in a more than proportionate increase in output. Similarly, decreasing returns to scale occur when output increases by a smaller proportion than the increase in input.

INDIVISIBILITY: Inability to divide certain factors of production into smaller units and, hence, to make marginal changes in its use.

INFANT INDUSTRY: Is one facing difficulties in its early stages but with promising potential in the future. Government assistance at the start may be justified if the industry is likely to outgrow such assistance later on.

INPUT: An input is a factor of production required to produce an output, for example, fry or fingerlings are an input needed to produce an output of fish. Inputs can be either variable or fixed.

ISOQUANT: A curve in input space showing all technically efficient combinations of inputs capable of producing a given level of output.

LAW OF DIMINISHING RETURN: If successive units of one input are added to given quantities of other inputs, a point is eventually reached where the addition to output per additional unit of the variable input will decline.

LONG RUN: That period of time (or planning horizon) in which all inputs can be varied (i.e., no fixed inputs).

MARGINAL: The word "marginal" refers to small changes in value rather than absolute values; that is, incremental change either discrete or continuous.

MARGINAL COST: The change or addition (increase or decrease) to total cost resulting from an additional unit of output.

MARGINAL (PHYSICAL) PRODUCT: The addition to total (physical) product attributable to the addition of one unit of the variable input to the production process, the fixed input remaining unchanged.

MARGINAL RATE OF SUBSTITUTION OF X FOR Y: Is the number of units of good (or resource) Y that must be sacrificed (or released) for each additional unit of good (or resource) X consumed (or used) to maintain a given level of satisfaction (or output).

MARGINAL RATE OF TRANSFORMATION OF X INTO Y: Is the number of units by which the production of X must be decreased to increase the output of Y by one unit.

MARGINAL REVENUE: The change (increase or decrease) in gross revenues resulting from an additional unit of output.

MARKET FAILURE: Is a malfunctioning of free markets resulting in distorted prices that do not reflect the true scarcity of resources and goods and, hence, result in a misallocation of the society's scarce resources.

MARKET IMPERFECTIONS: Is the lack of "sufficient" competition among the suppliers or buyers of a good or a resource, e.g., monopoly, monopsony, oligopoly, monopolistic competition, etc., resulting in distorted market prices and, hence, in inefficient allocation of resources.

MEAN OR AVERAGE: The sum of the observed values divided by the number of observed values. Also known as the arithmetic mean.

NET REVENUE: Gross revenue less total costs.

NONCASH COSTS: No money or cash outlay is required or spent in the use of the input owned by the producer.

OPPORTUNITY COSTS: The return given up by not participating in the next best alternative activity.

OUTPUT (PRODUCTION) ELASTICITY: Given the production function, the output elasticity of X is the proportional change in output resulting from a given proportional change in X, other inputs held constant. The output elasticity of an input is equal to its marginal product divided by its average product.

PARETO OPTIMUM: Is a situation where it is not possible to make even one person better-off without making someone else worse-off. Pareto optimum is the most efficient allocation of resources and goods under the prevailing distribution of wealth.

PARTIAL BUDGETING: A recalculation of additional costs and additional returns or reduced costs and reduced returns as a result of a minor change in a production technique.

PAYBACK PERIOD: Number of years required to recover the initial investment.

PRIVATE BENEFIT: The benefit accruing to individual farmers from the sale and home consumption of the goods and services they produce. Market prices are used in valuing these outputs.

PRIVATE COST: The cost incurred by the individual farmer in employing a factor of production (owned and purchased) to produce a given level of output. The prevailing market prices are used in costing these inputs.

PRODUCTION FUNCTION: An input–output relationship showing the maximum amount of output that can be produced from any specified set of inputs, given the existing technology.

PUBLIC GOOD: Is a good whose consumption by one individual does not diminish its availability to other individuals. A public good is, thus, characterized by jointness in supply, in that to produce it for one consumer it is necessary to produce it for all consumers. In many cases, no one can be excluded from the enjoyment of a public good whether the individual pays or not (e.g., national defence or control of epidemic fish diseases).

RATE OF RETURN ON CAPITAL INVESTMENT: Returns to capital divided by capital investment.

RETURN TO CAPITAL: Gross revenues less total costs except the opportunity cost of capital.

RETURN TO LABOUR AND MANAGEMENT: Gross revenues less total costs except those associated with the operator's labour and management.

RETURN TO LAND: Gross revenues less total costs except those associated with land costs.

RETURNS TO SCALE: The percentage change in output that results when all inputs are expanded by a certain percentage. The returns to scale can be obtained by adding the output elasticities of all the inputs in the Cobb-Douglas production function. Returns to scale can be either increasing, constant, or decreasing.

SECOND BEST: Is a situation where market distortions are so pervasive that the restoration of a first-best situation is not attainable and, hence, it is necessary to make allowances for suboptimality in the assessment of costs and benefits.

SENSITIVITY ANALYSIS: Recalculation of economic viability under alternative sets of input–output prices and yields.

SHORT RUN: That period of time in which the input of one or more productive agents is fixed.

SOCIAL BENEFIT: The benefit accruing to the society as a whole from the production and use of certain goods or services and related by-products. In valuing these outputs, social or shadow prices reflecting their true value to the society are used. Markets may fail to assign prices to certain "outputs" e.g., pollution.

SOCIAL COST: The cost incurred by the society as a whole in terms of use of scarce resources (or sacrificed alternatives) for the production of certain goods or services. Social or shadow prices reflecting the true scarcity of resources are used in calculating costs. Market prices reflect the true scarcity of resources only under ideal conditions of perfectly functioning markets.

STRAIGHT-LINE DEPRECIATION: Annual depreciation equal to purchase price of an asset less any salvage value of it divided by the expected years of life.

TOTAL COST: In the short run, total cost is the sum of total variable and total fixed costs. Total variable costs and total fixed costs are related to variable and fixed inputs, respectively.

TOTAL FIXED COSTS: Costs of input that do not increase or decrease with the level of production, such as land lease, interest, insurance premiums, depreciations, salaries of permanent personnel, etc.

TOTAL (PHYSICAL) PRODUCT/OUTPUT: The total (maximum) output obtainable from different amounts of the variable input, given a specified amount of the fixed input.

TOTAL VARIABLE COSTS: Costs of input that increase or decrease with the level of production, such as fry, feed, fertilizer, electricity, temporary labour, etc. Total variable costs are sometimes called operating costs.

TRANSACTION COSTS: Are the expenses necessary to bring together the suppliers and the buyers of goods and services and effect all beneficial exchanges.

UNCERTAINTY: A situation in which more than one outcome is possible from any given action. If no objective probability to each of the many outcomes can be assigned we talk simply of uncertainty. If the probability of each outcome can be inferred we talk of risk.

VALUE OF AVERAGE PRODUCT: The value of the average product of a variable input is equal to its average product multiplied by the market price of the output.

VALUE OF MARGINAL PRODUCT: The value of the marginal product of a variable input is equal to its marginal product multiplied by the market price of the output.

VARIABLE INPUT: An input whose quantity can be changed almost instantaneously in response to desired changes in output.

WELFARE MAXIMUM: Is a situation where no conceivable change can improve the well-being of the society given its resources and the state of technology and knowledge.

Appendix 2:

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